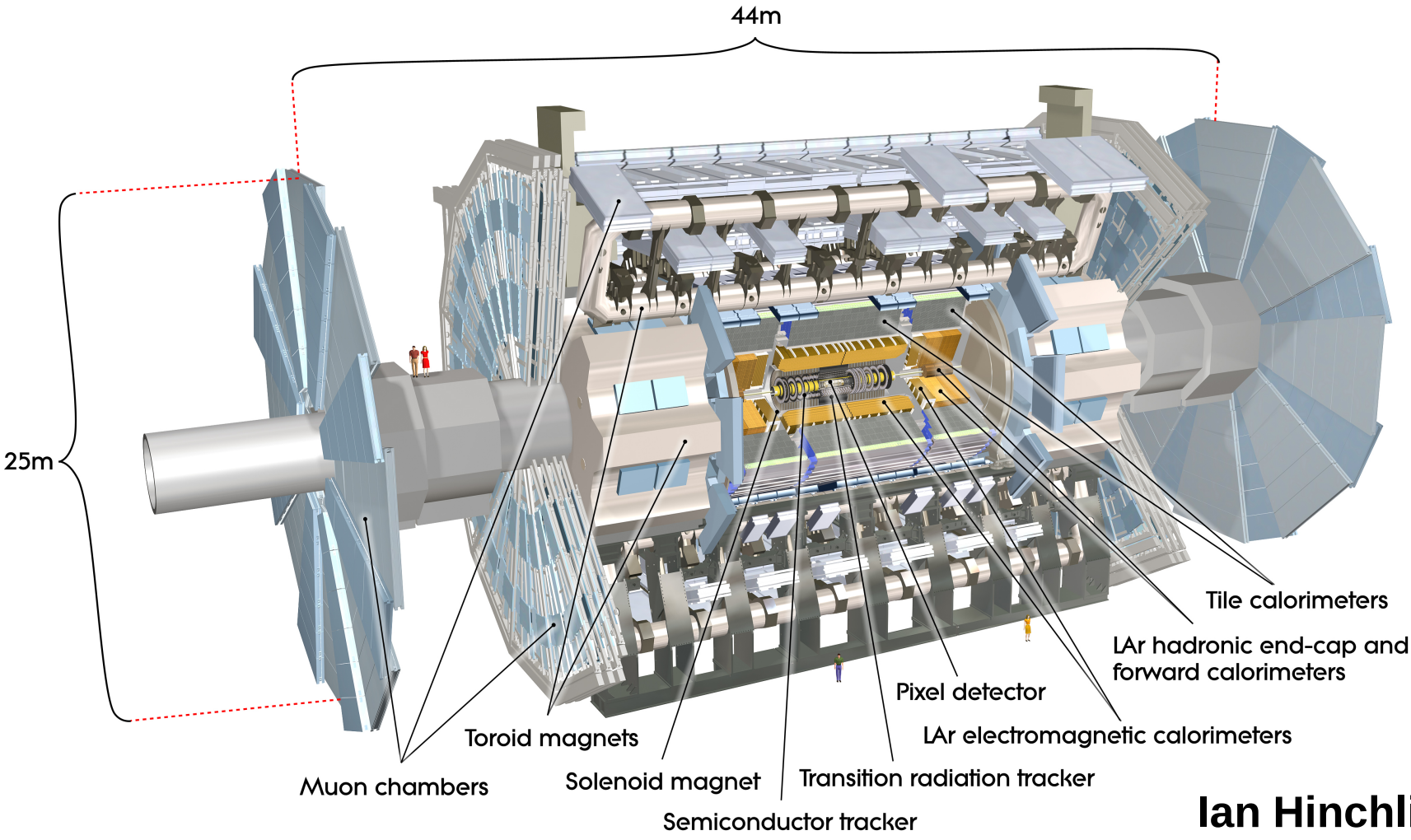
New Physics with ATLAS



Ian Hinchliffe

4 Sept 2011

Outline

Motivation: what we are looking for.

Status of ATLAS data taking

Some comments on standard model processes

Some examples of new physics searches

List of processes and models with limits

No Higgs today (you can ask at the end)

The fundamental questions of HEP

- **The mass problem**
  - **Why are some particles heavier than others?**
  - **How do they get mass?**
- **The matter anti-matter problem**
  - **We are made of matter not anti-matter**
  - **The early universe had both matter and anti-matter: what happened?**
- **The Dark matter problem: what is it?**
  - **Makes up ~20% of observed matter(energy) in universe**
- **The Dark energy problem: who ordered that?**
  - **Makes up ~75% of observed energy in universe**
- **LHC is expected to contribute to all these (except the last one)**

The Standard Model

- **Should really be called a theory (like “theory of relativity”)**
- **Developed over last 40 years**
- **Describes all interactions**
  - **Except gravity**
- **Calculations and measurements agree to 0.00001%**
- **It is incomplete**
  - **Neutrino oscillations: neutrinos must have mass, can be added in an unappealing way**
  - **Muon (g-2) may disagree with predictions: is this result definitive.**
  - **.....**

The Standard Model unsatisfactory

- Cannot explain some phenomena
  - No understanding of mass ratios
  - Neutrino masses (can be fixed in an ad-hoc way)
- Mechanism of mass generation not tested
  - Could be manifest as a Higgs boson (coming next)
  - Or something more complicated
- Too many arbitrary parameters (18)
  - Must be determined by experiment
- Forces not unified
  - What explains their relative strengths
- What about (quantum) gravity?

Many theoretical ideas

- **Standard model Higgs**
  - **Not very satisfactory but**
  - **Well defined. Must find or exclude it.**
- **Composite scalars**
  - **Higgs not elementary**
  - **More new states**
- **Supersymmetry**
  - **Some particles must be less than TeV**
  - **Otherwise not relevant to hierarchy problem**
  - **Many new states to look for**
- **Strongly coupled W/Z sector at high energy**
  - **Cannot say anything yet**
  - **Need 14 TeV**
- **Extra dimensions:**
  - **Lowers fundamental scale of gravity**

Hierarchy Problem

SM constrained at the loop level by precise data from LEP, W mass *etc*

New particles of mass < 10 TeV are constrained: EW fits FCNC limits *etc* unless their couplings are very well prescribed.

Cannot add new particles LHC range unless they respect the constraints

Hierarchy Problem II

Compute corrections to Higgs mass with a momentum cut off Λ

Three most important contributions are

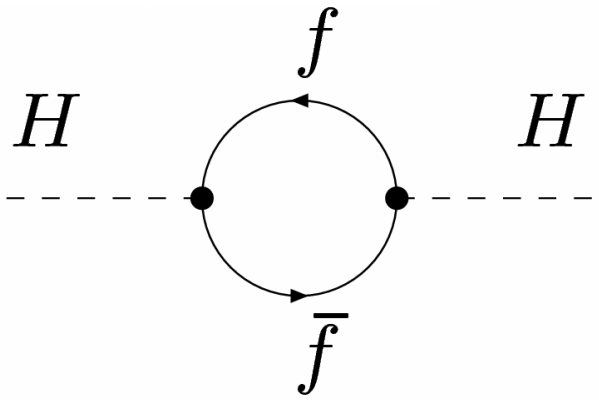
Top quark loop $\delta m_h^2 = \frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \sim (2TeV)^2$

W loop $\delta m_h^2 \sim \alpha_w\Lambda^2 \sim -(750GeV)^2$

Higgs loop $\delta m_h^2 \sim \frac{\lambda}{16\pi^2}\Lambda^2 \sim -(1.25m_h/100GeV)^2$

Natural sum of these is 1 TeV

But.....



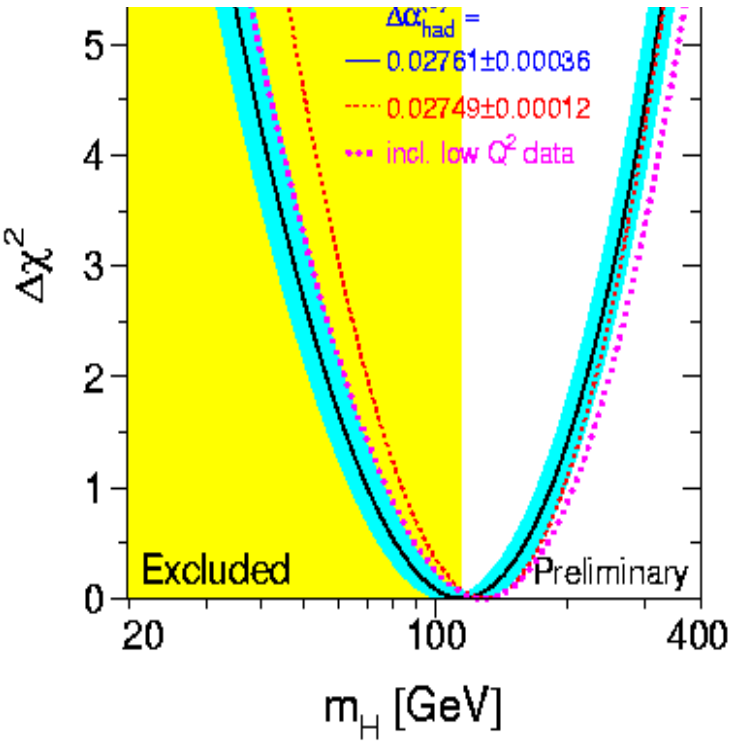
Hierarchy Problem III

But Higgs is supposed to be <200 GeV

"I'll just adjust bare mass to get right answer"

"Its no big deal"

Better is to get rid of big effects by canceling them: this implies new particles



The experimental challenge

We don't know what the new states are but

When particles will decay into the particles of the Standard model, therefore we must measure them.

leptons (electron, muon, tau and neutrinos)

gauge bosons: W, Z photon, gluons
quarks

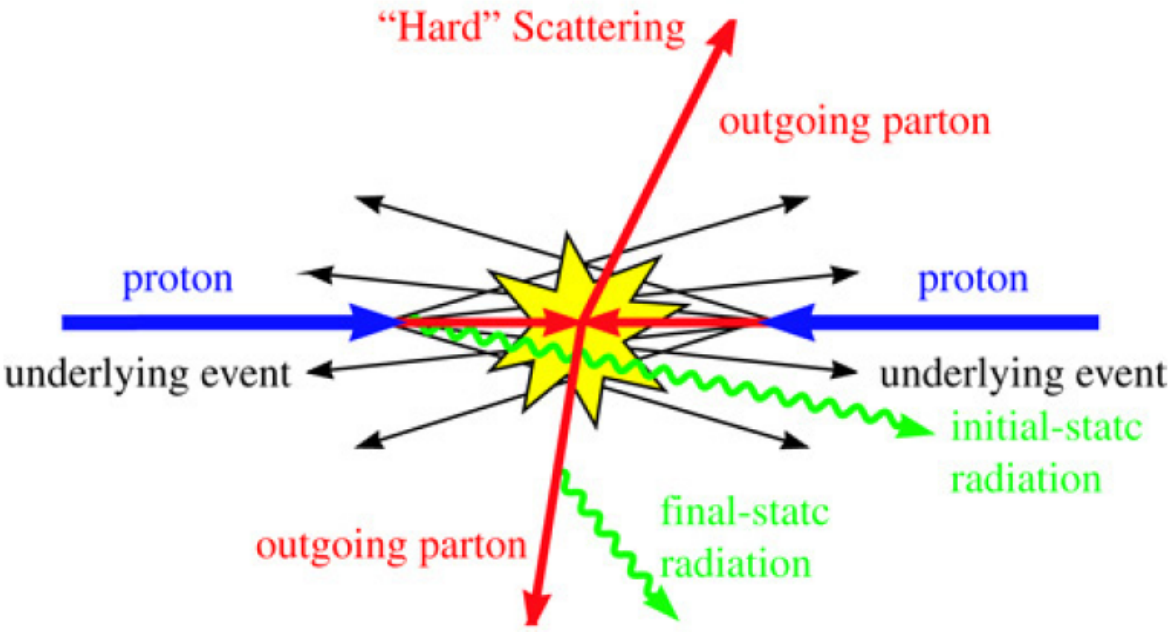
Want comparable precision for all (if possible)
For example violation of e/mu/tau universality can signal new physics

Lots of standard model physics processes to measure
If these look wrong, you should not believe any claims about new physics: either limits or discoveries

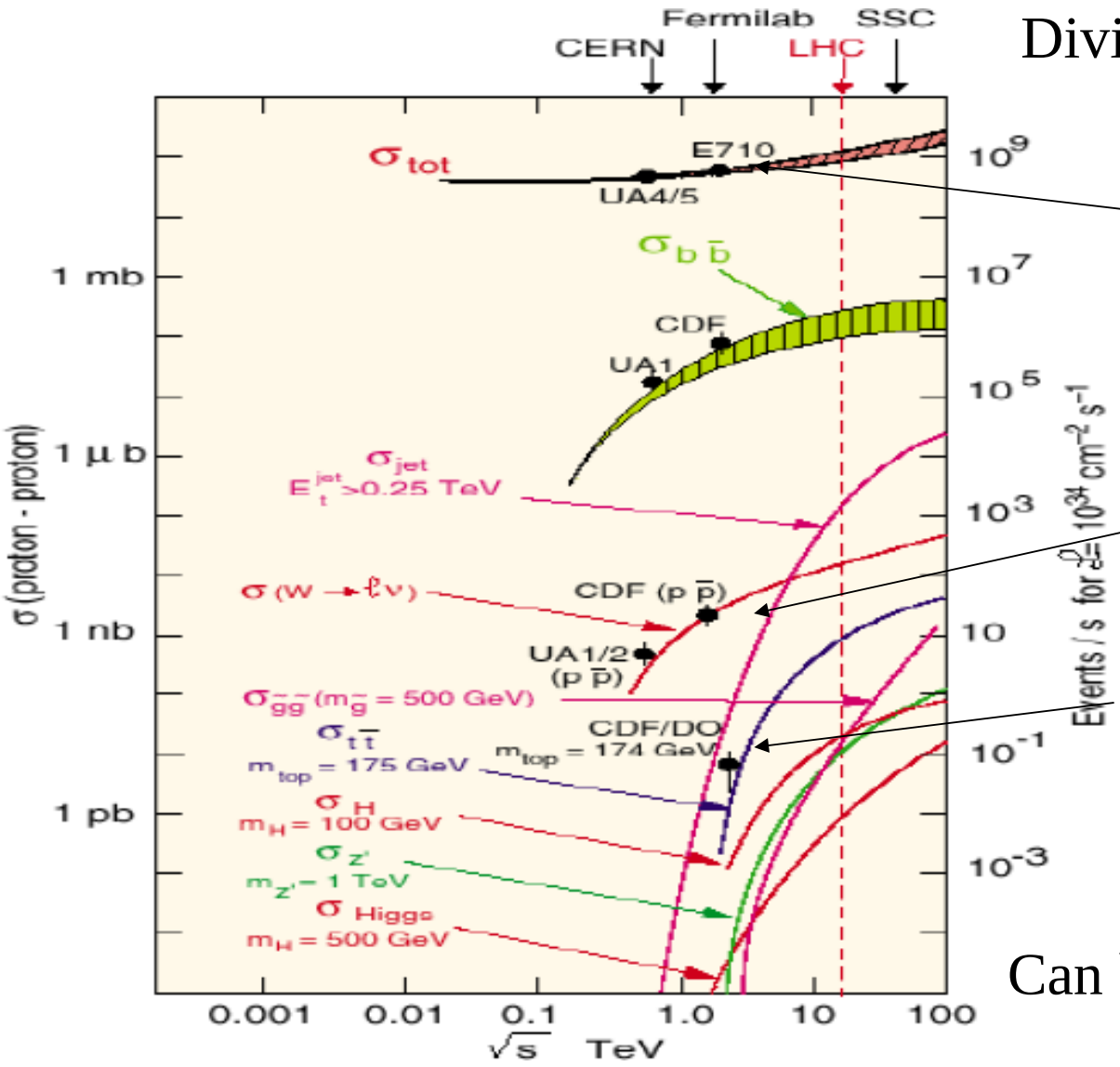
The measurements

A very large range of processes and rates

- **Cannot measure every event**
- **Too much data**
- **Not enough bandwidth, CPU or storage**
- **Must get interesting events, throw the rest out**
  - **Be careful, gone forever, don't loose the Higgs**
- **This is the trigger issue**



Rates today (approx)



Divide scale by 3

300 MHz total rate

15 Hz for W

0.3Hz for top quark

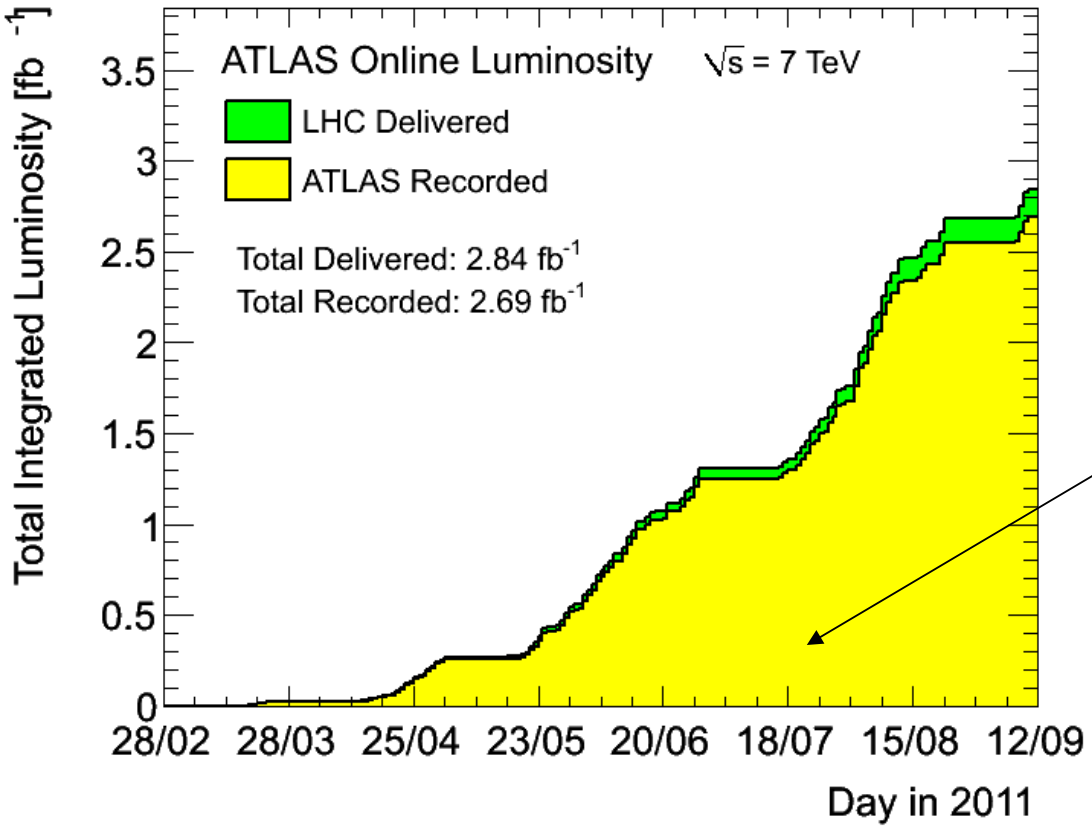
Can keep only 300 Hz

Physics at last: Its been quite a year!

- Data taking started in 2010
- More than 50 papers submitted to journals
- Results with 1 inverse fb shown at EPS in July 2011
  - Tevatron new physics limits all exceeded
  - LHC Higgs searches more sensitive than Tevatron

- Another inverse femto-barn of data taken since EPS
- Really impressive turn around. Data taken is processed and results released publically within 4 weeks!
  - Its getting hard for me to keep up

Data taken

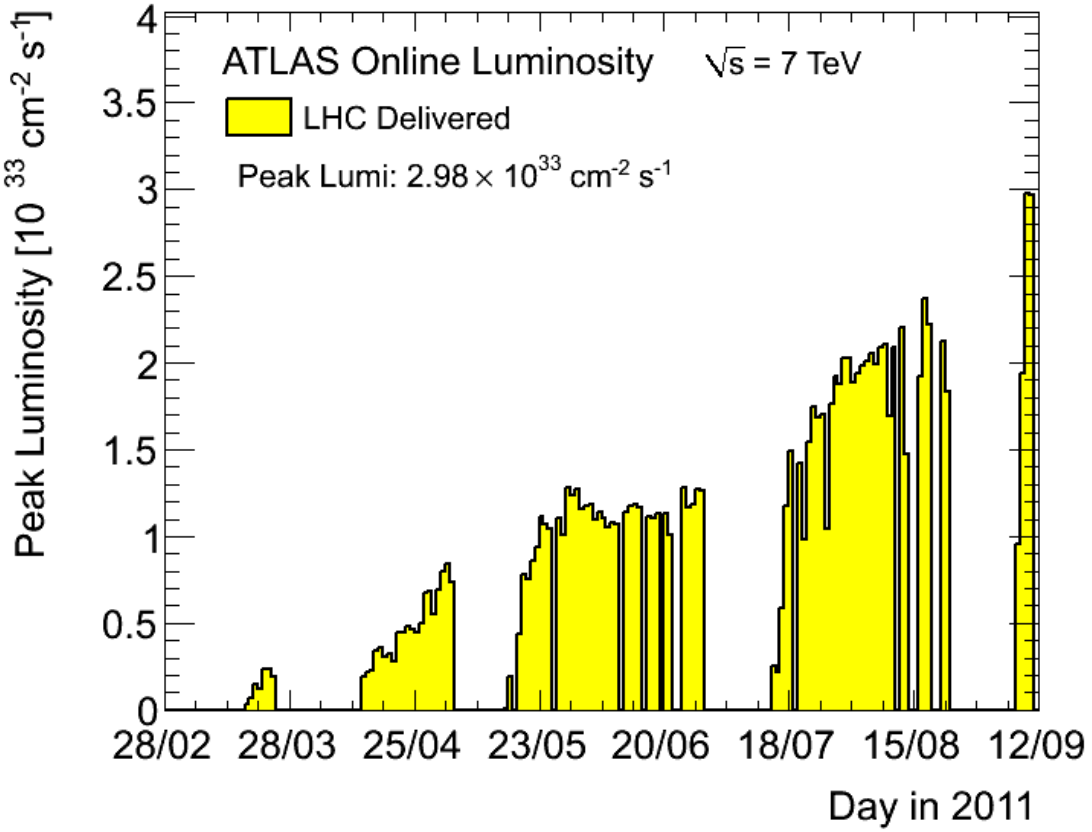


1.1 inverse fb EPS

Figure updated daily by Data Prep, so you can see how we are doing

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResults#2011_pp_Collisions

Data taken



Pile-up has arrived much earlier than expected. >8 interactions/crossing

Some issues with detector performance

It's been quite a year for the Berkeley group

Three LBNL student theses (all published as papers)

Major LBNL physics involvement in publications in

- QCD/strong interactions
  - Inelastic cross section (published)
  - Upsilon cross section (published)
  - Jet Fragmentation (1 published, 1 paper in final internal review)
  - Jets in Heavy Ions (published)
  - J/Psi in Heavy Ions (published)
- Electroweak
  - ZZ and WZ (in preparation)
  - WW cross section (published)
- Top
  - Cross section (published)

It's been quite a year! (page 2)

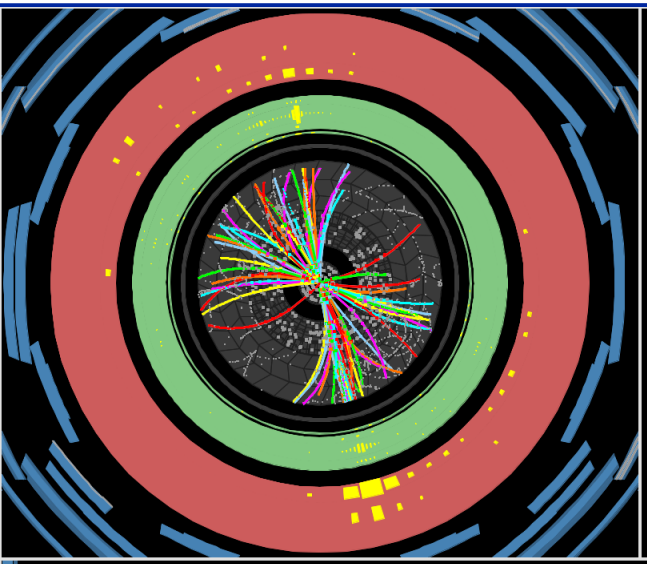
New Physics searches

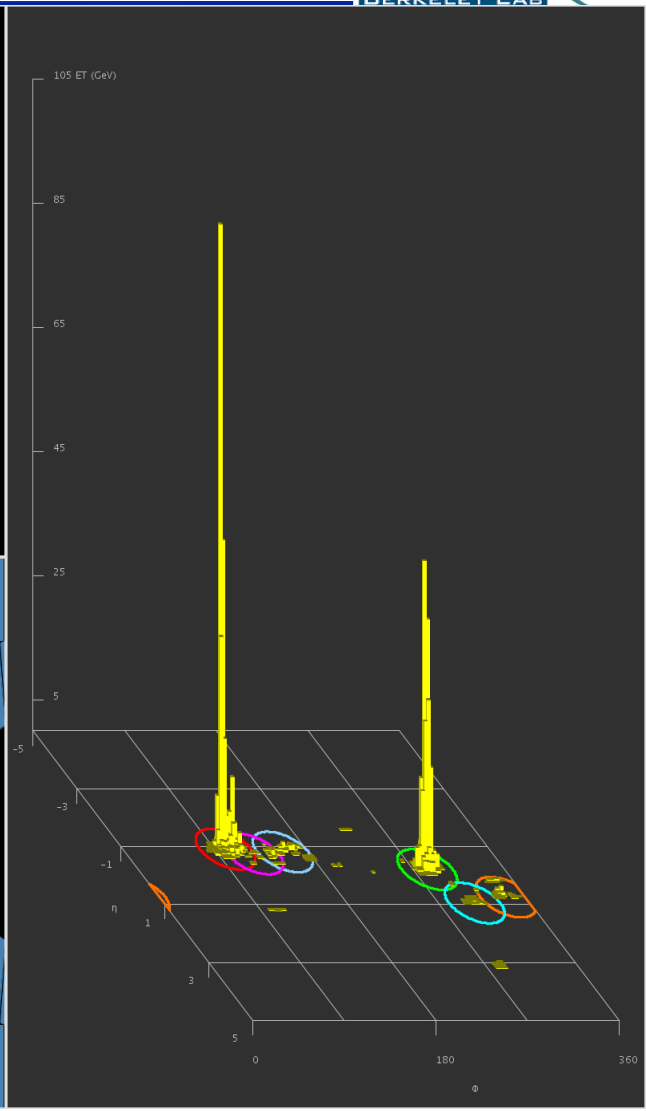
- **Same sign dimuons (conf result in final review)**
- **Black Holes (conf result for Moriond, 2011 paper in preparation)**
- **Higgs to tau tau (conf result in review)**

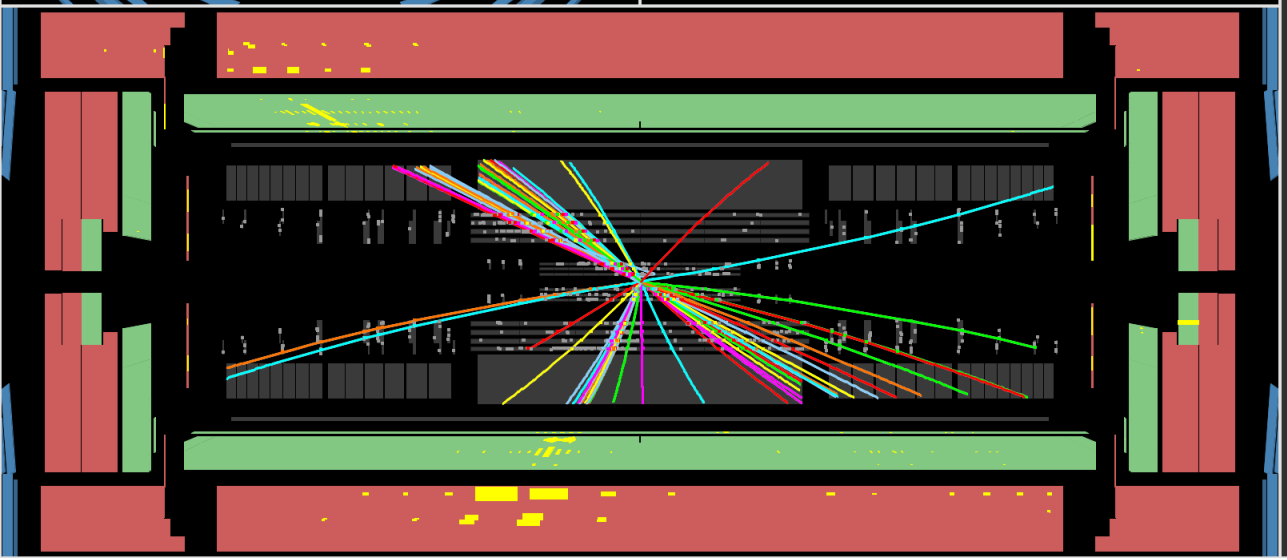
Reviewers of other analyses

- **Susy**
- **Monojets (extra dimensions)**
- **Right handed W`**

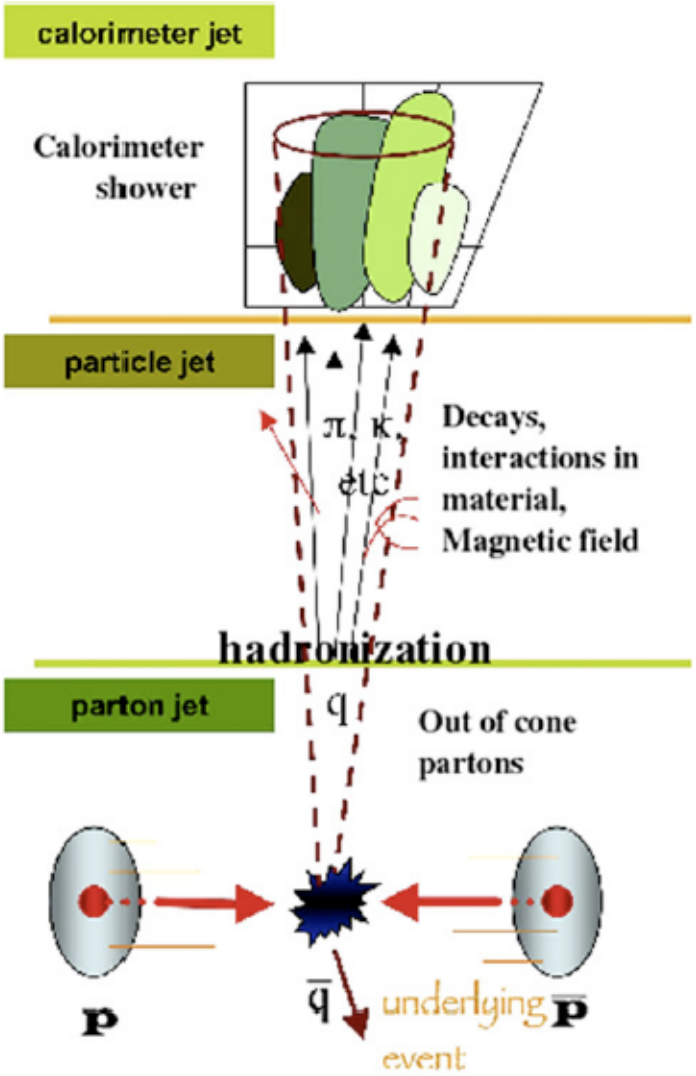
Many events look like this







It's this fundamental process



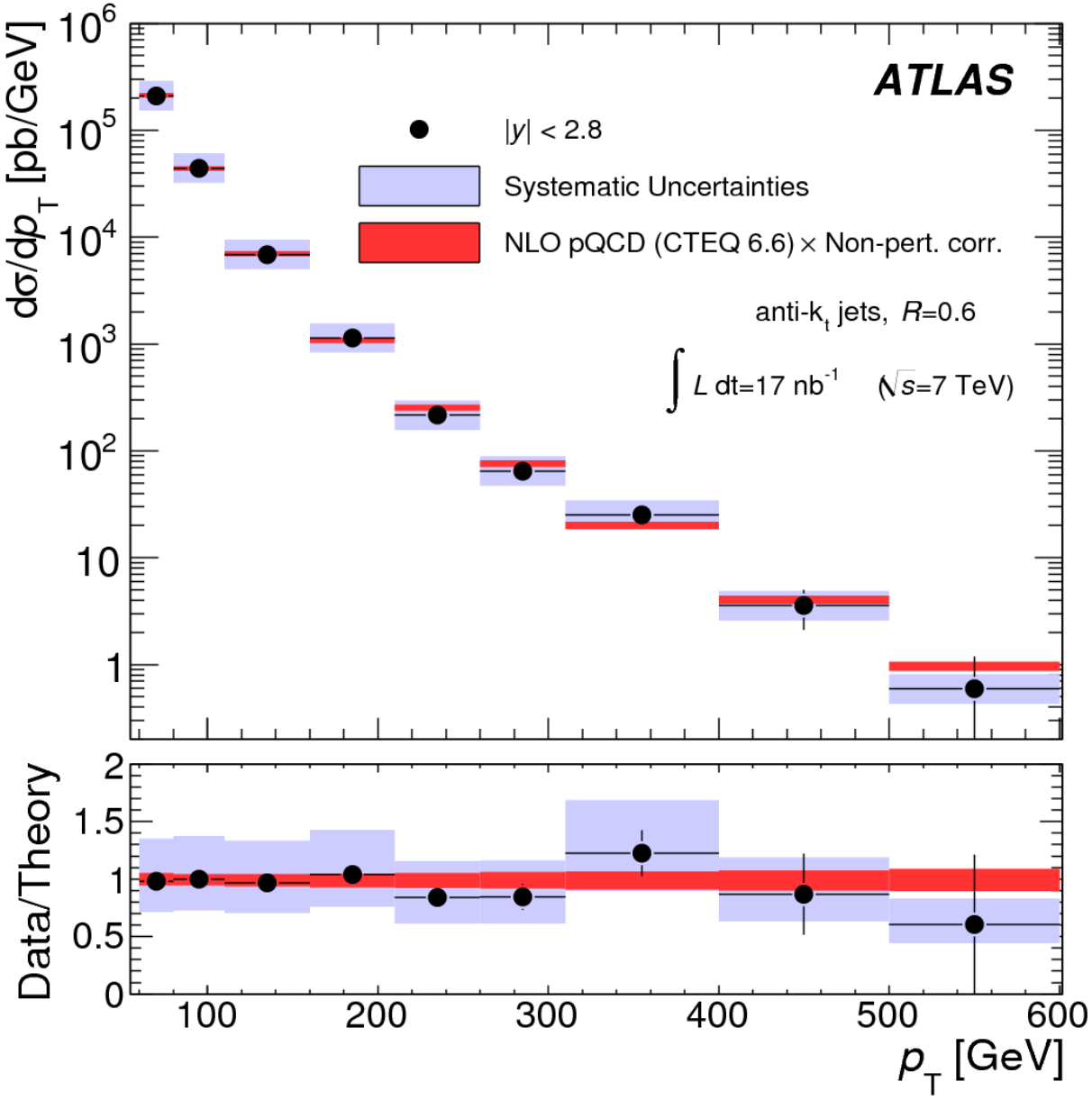
Fundamental process is Quark and gluon scattering

This can be calculated

Is it correct?

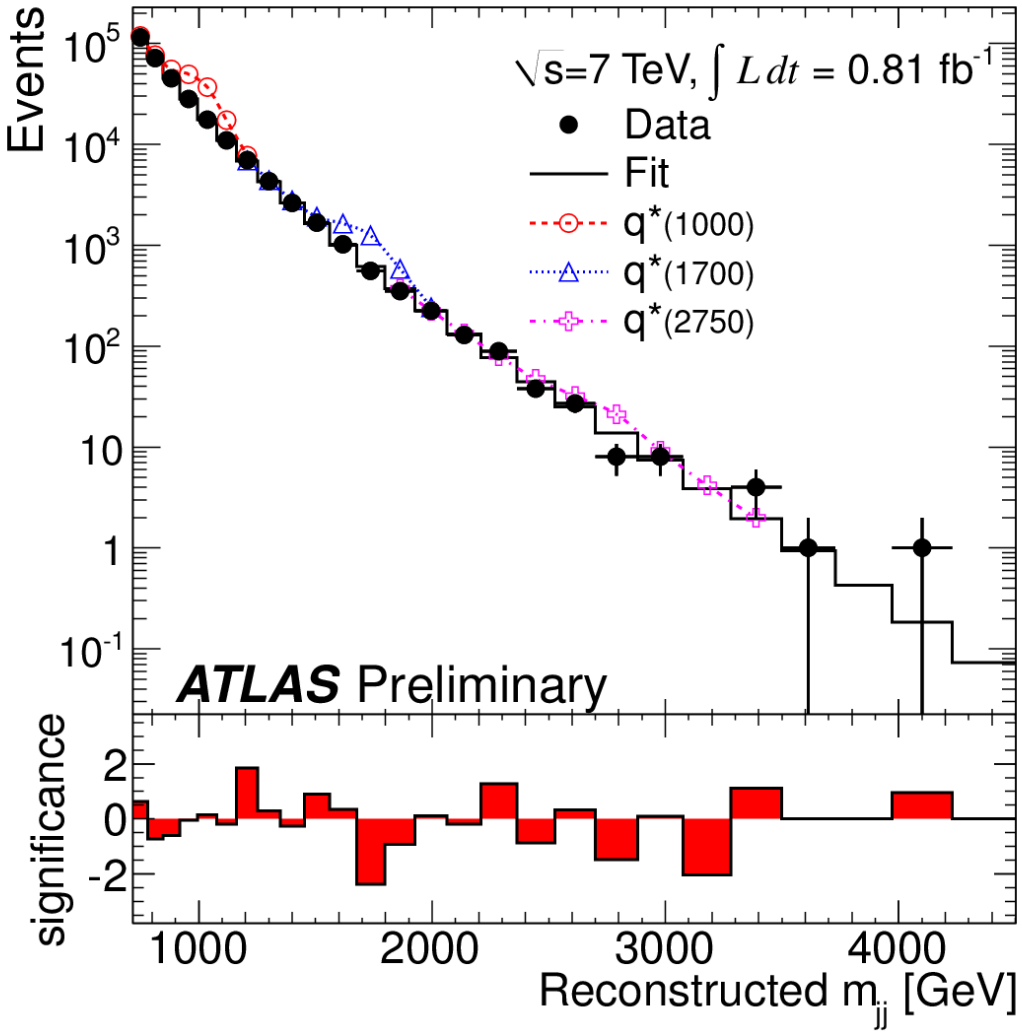
Thanks to J Huston

Huge dynamic range



Prediction works!

Using jets to look for new physics



A particle decaying to two quarks would appear as a bump in this spectrum

The signals shown are excluded

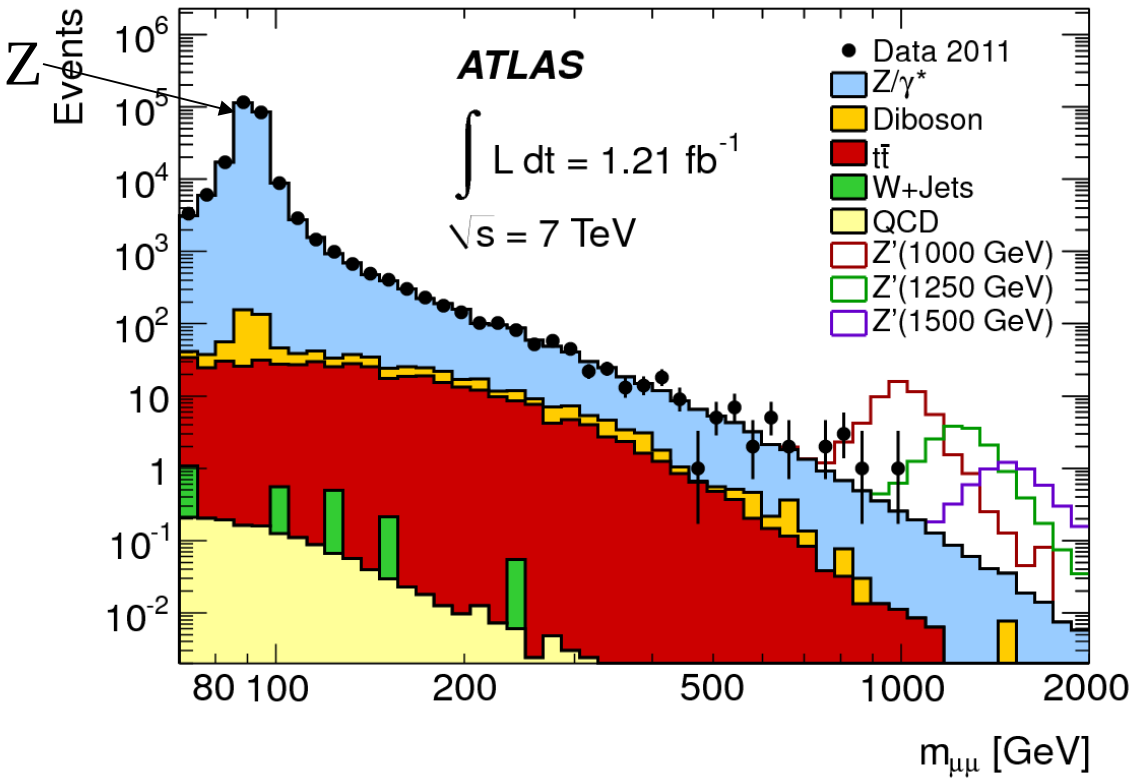
Final states with leptons

Most important are leptons that are isolated
These come from decays of heavy states
Standard model sources are
W decays
Z decays
Direct production (low rate)

Leptons only (very simple final state) then

I'll discuss top quark production

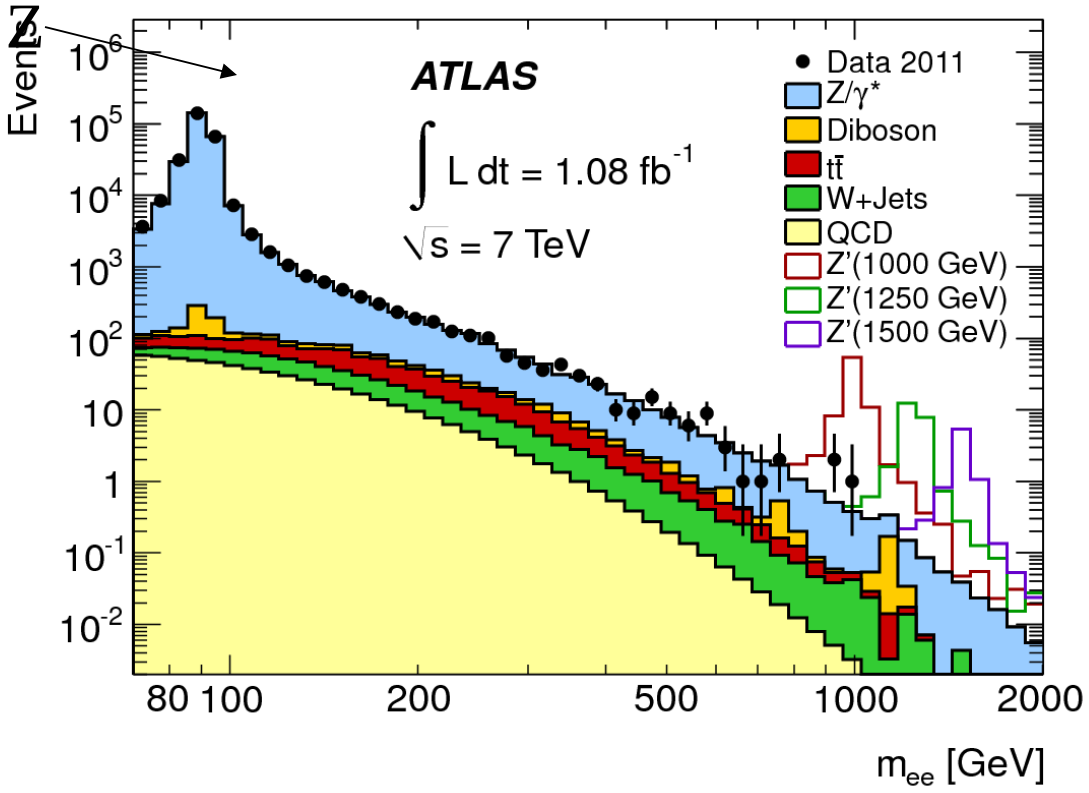
Simple final states with leptons



Invarient mass of two muons

No more peaks beyond the Z

Simple final states with leptons

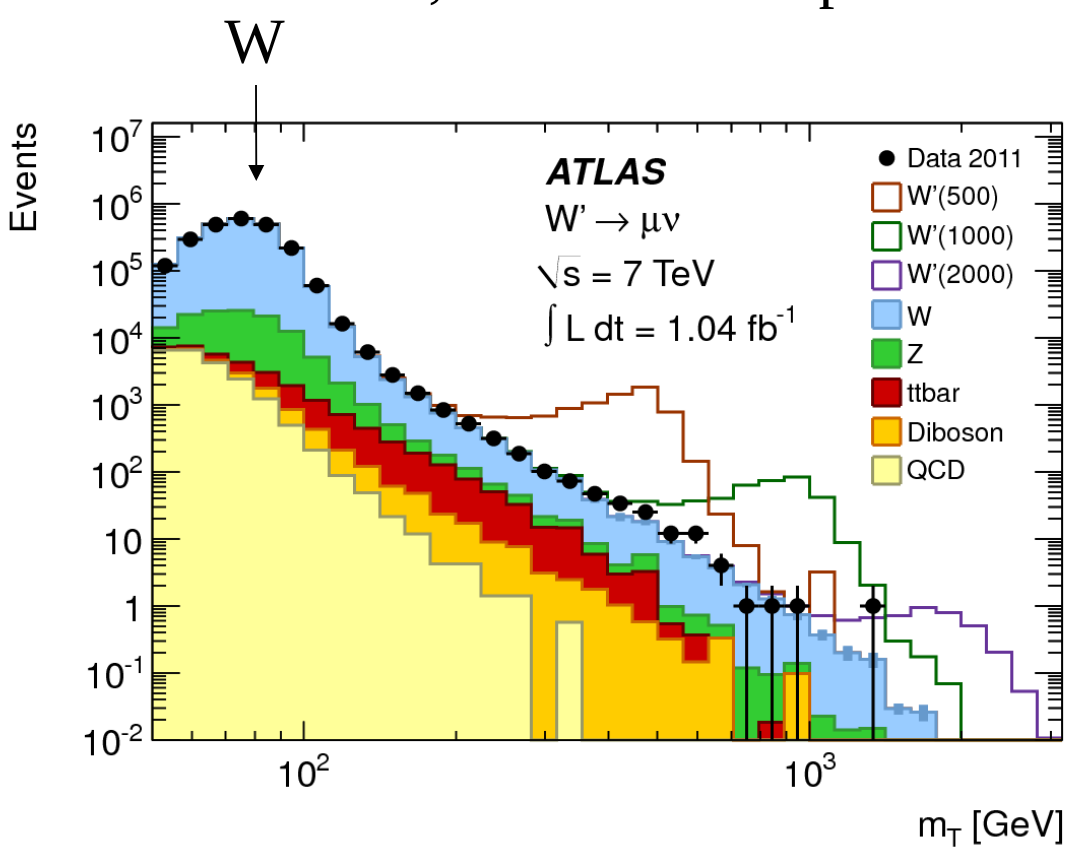


Invariant mass of e+e- pair

No more peaks

Simple final states with one lepton

Also look for missing transverse energy
If it comes from a neutrino, then almost a peak



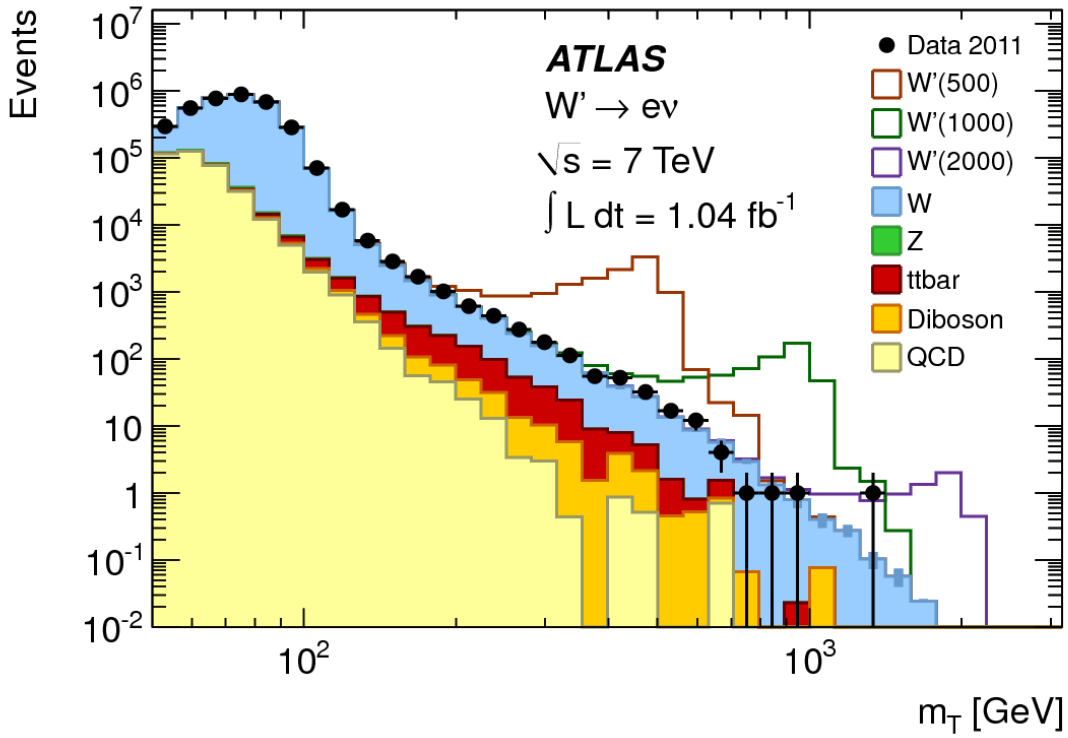
Mass made from transverse momentum components

Simple final states with one lepton

Also look for missing transverse energy

If it comes from a neutrino, then almost a peak

W



Mass made from transverse momentum components

Turning these into limits

If you have a model with something that decays to mumu or munu you can use this plot to constrain it

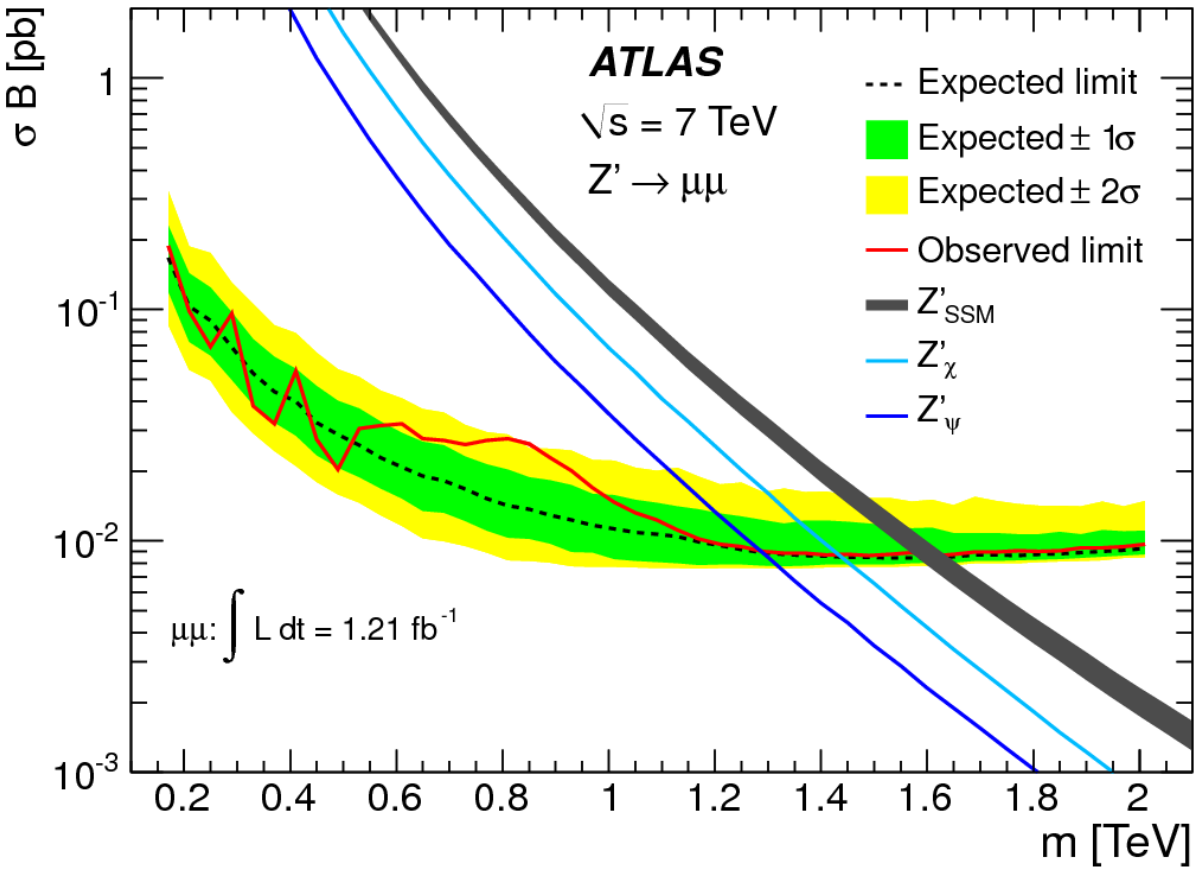
But search may not be optimal for your model

There is a trade off: general applicability vs more sensitivity

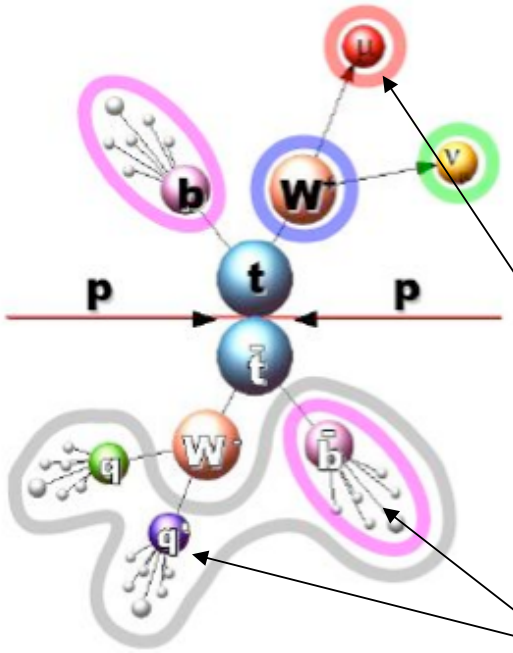
More complex final states mean that generic searches will be less sensitivity to a particular model

Limits on such resonances

In this case it's trivial to apply to a model.



Properties of top quarks



First observed at Tevatron

Production rate and decays predicted in standard model

All detector must work together

Muon system (muon)

Calorimeter (jets and neutrino)

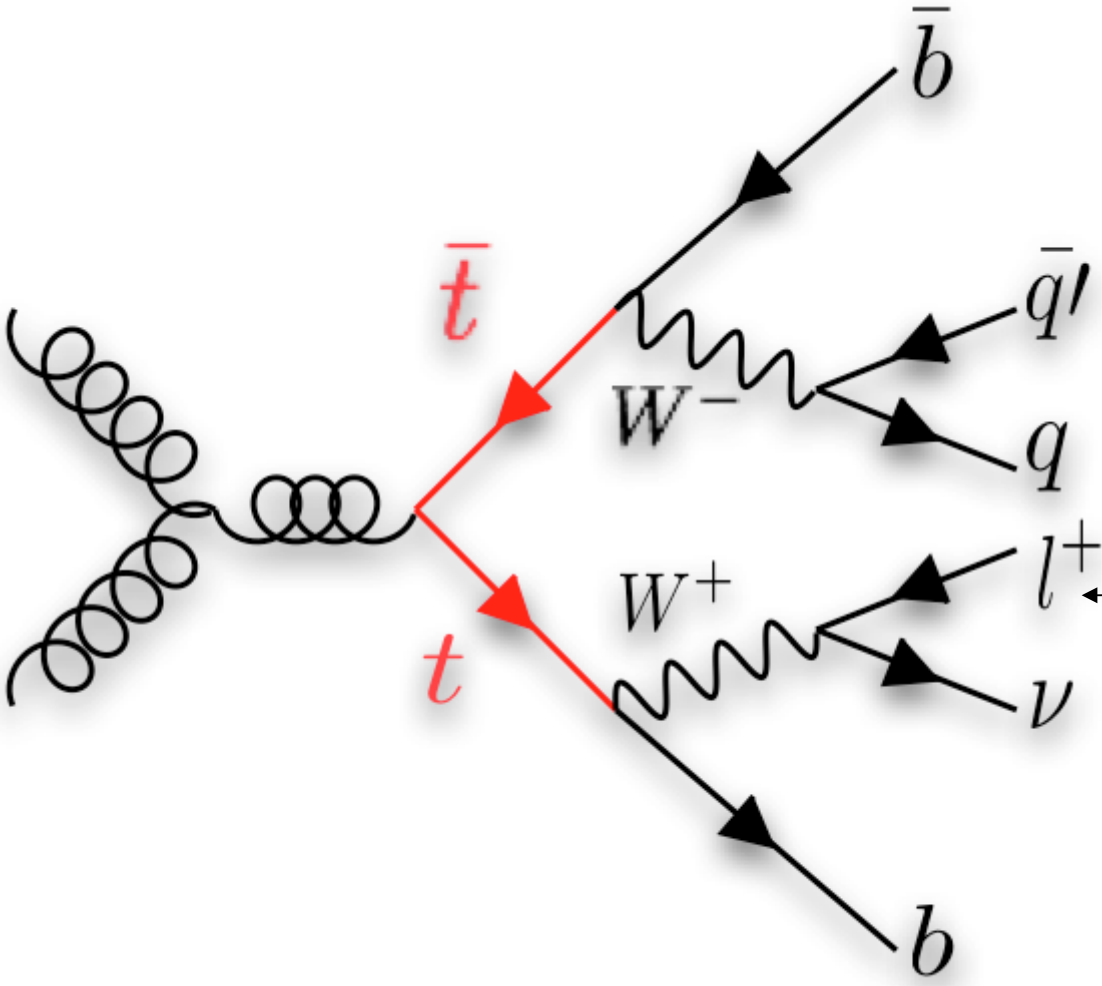
Tracking system (short lifetime particles from b-quarks

Made in pairs

Detect decay products

Reconstruct mass peak

Finding top quarks

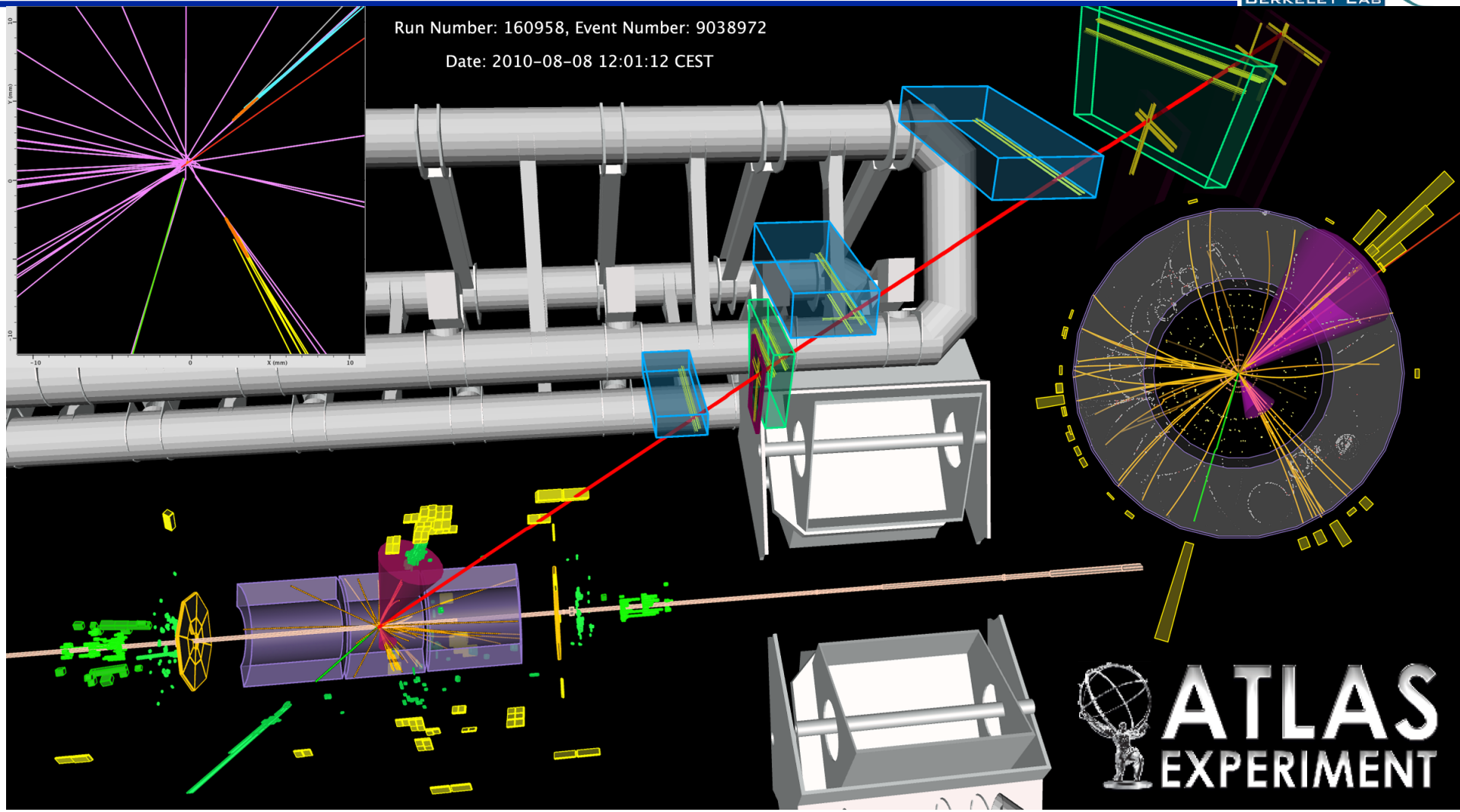


Characteristic feature

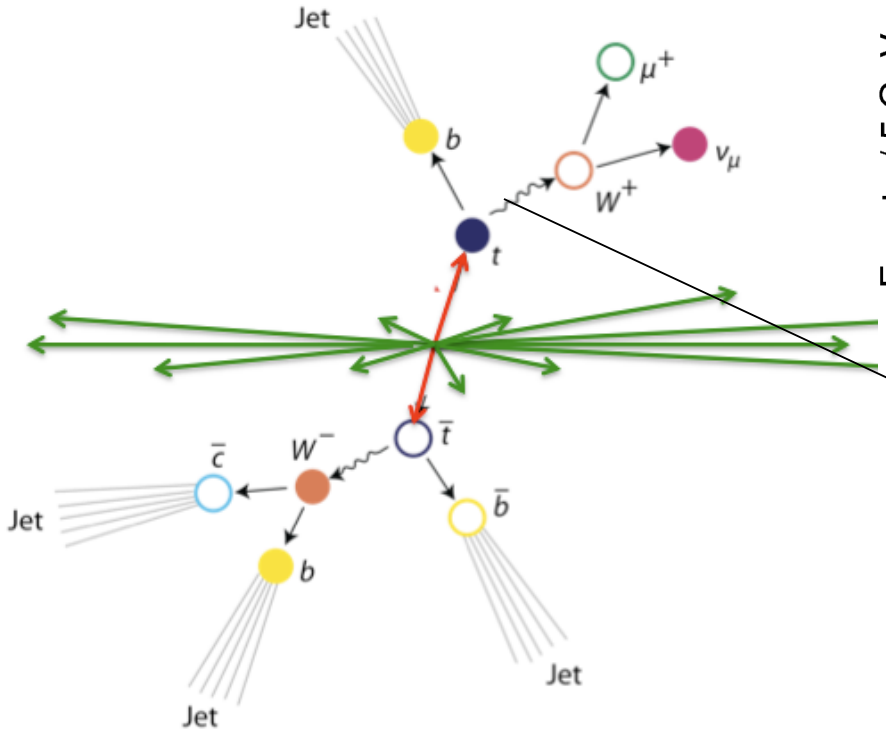
Look for two jets from W

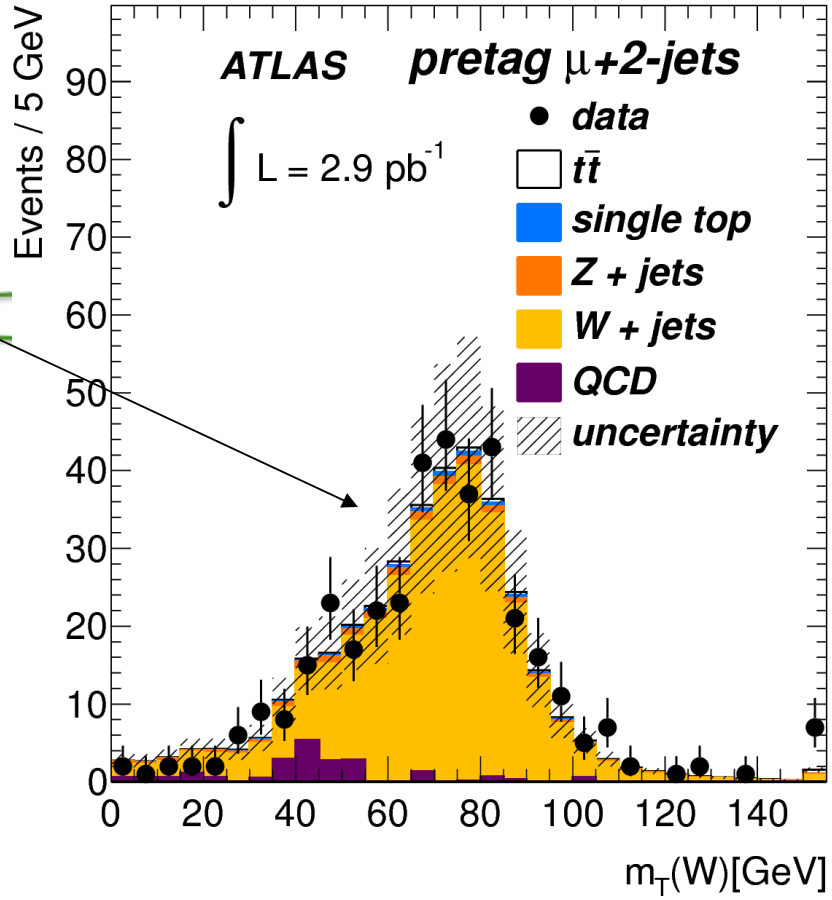
Select event using Muon Used in trigger

A very clean event



Do we have some W's in here?



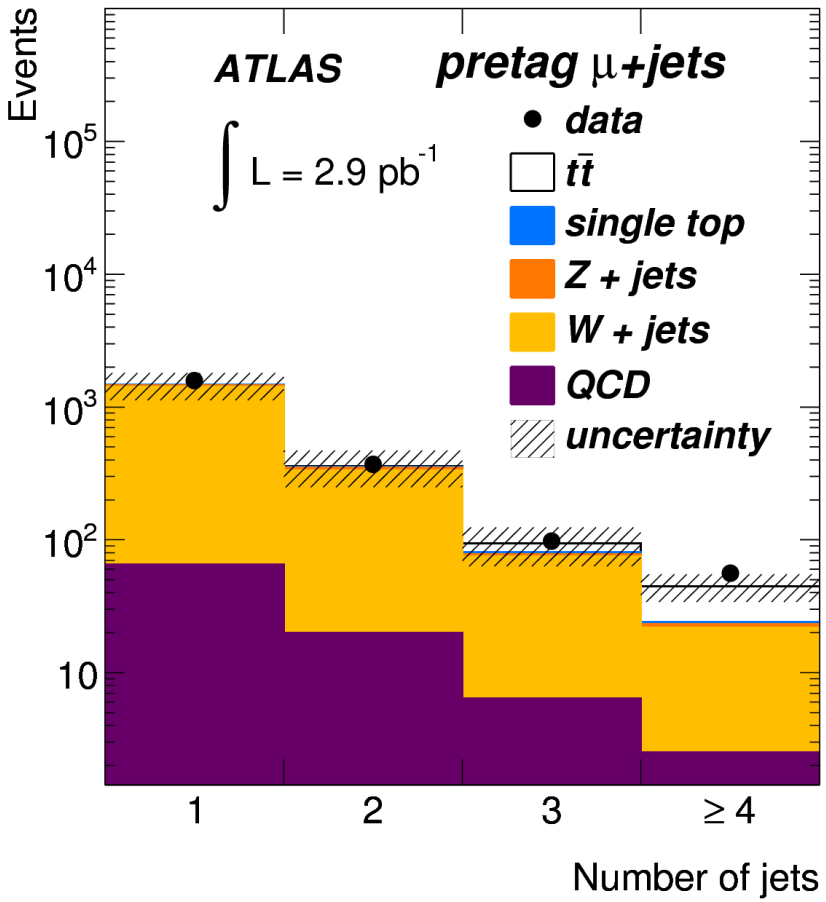


Add the muon and missing Et

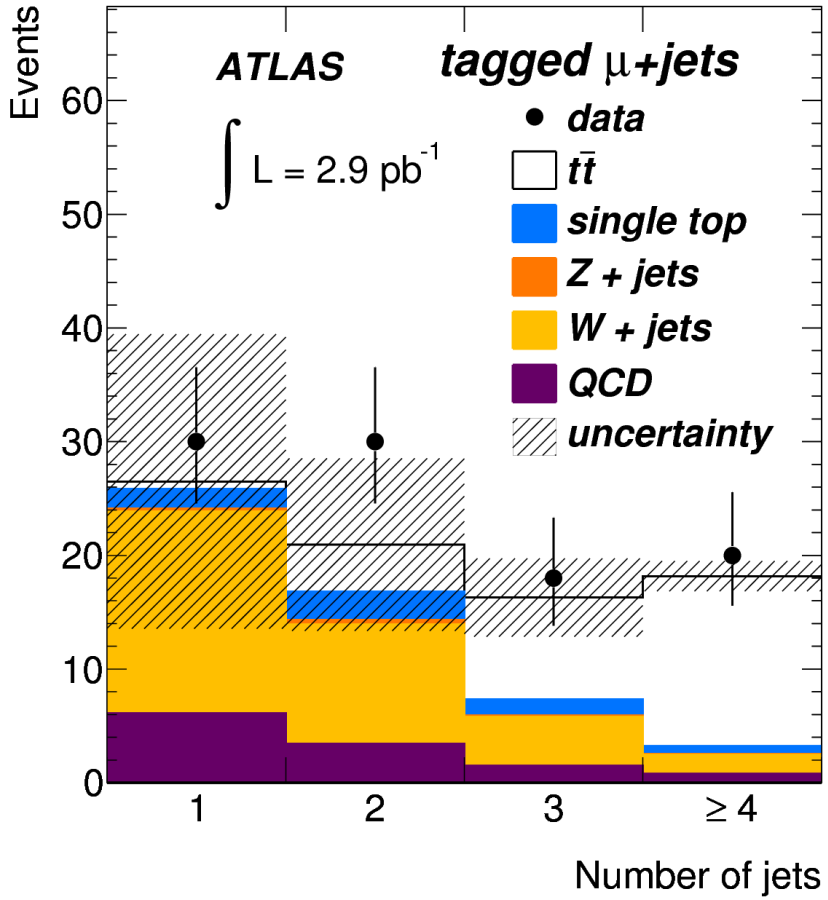
Mass of W is 81 GeV, not bad!

How many jets are there?

All jets



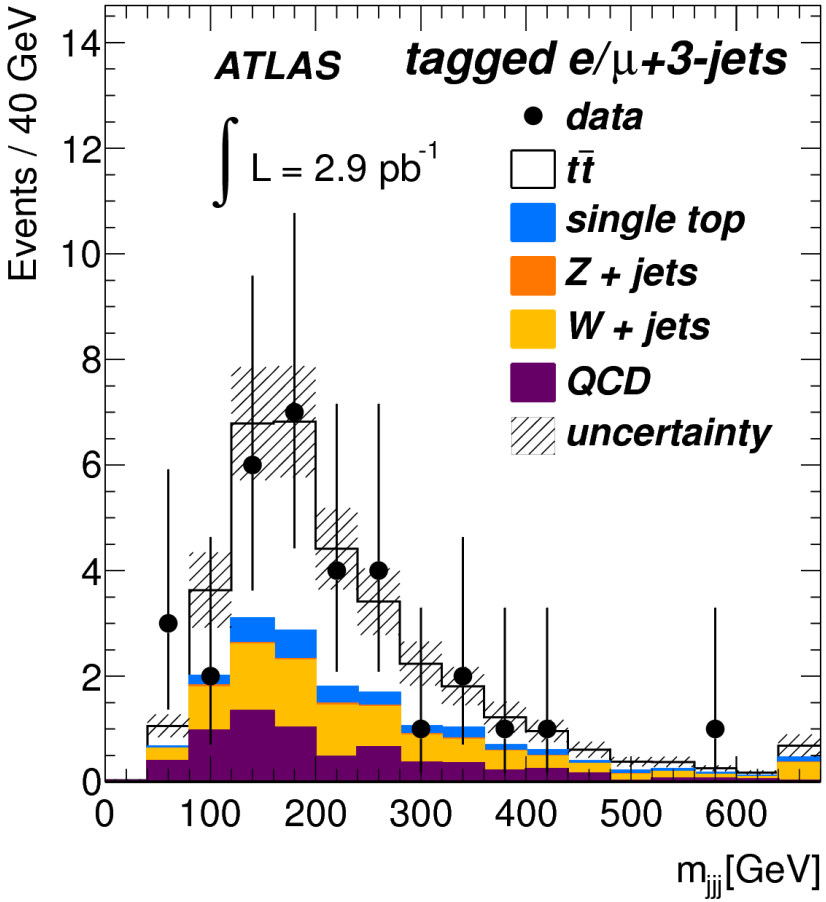
At least on jet from b quark



Is this a top?

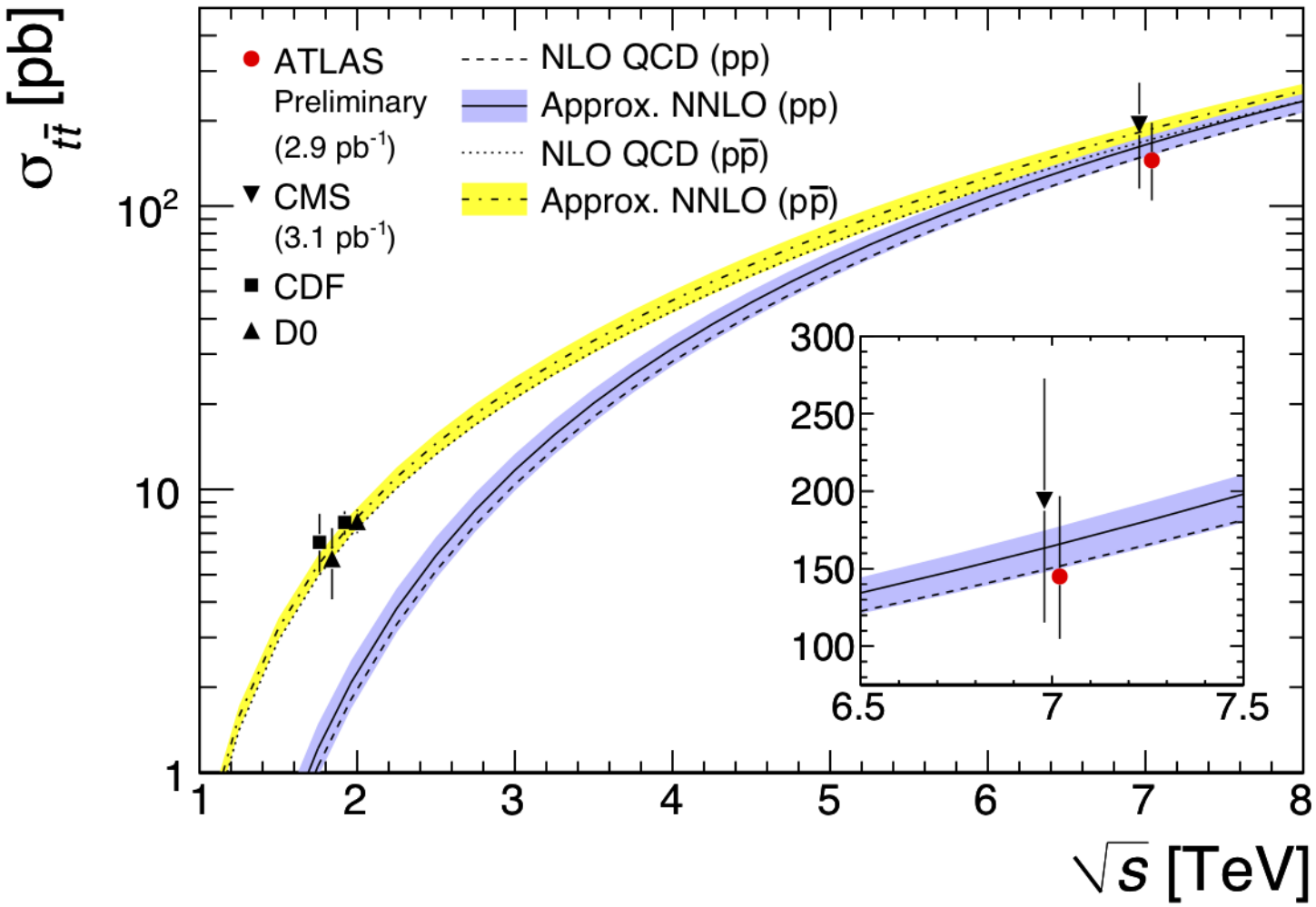
Mass of three jet System

~15 events in this plot
Another ~15K now!



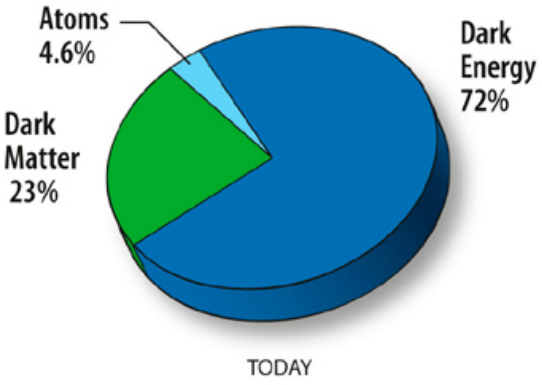
Peak at top mass of 174 GeV

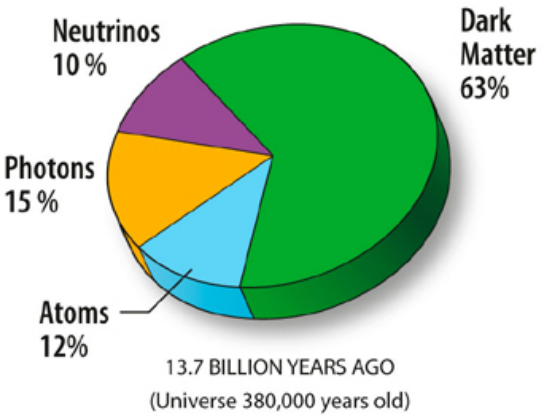
Measure the rate



Will the LHC see (SUSY) Dark Matter?

- **Astrophysical observations**
  - **Motion of stars and galaxies**
- **More "stuff" than we can see**
- **Universe is mostly not made of "stuff like us"**
- **Dark matter**
  - **Clumps near galaxies**
- **Could be cloud of particles**
  - **Must be very weakly interacting**
  - **Very sensitive experiments search for these**
  - **Mass should be about 100 times proton**
- **Could be produced directly at LHC**





How to search for susy

Generic signatures

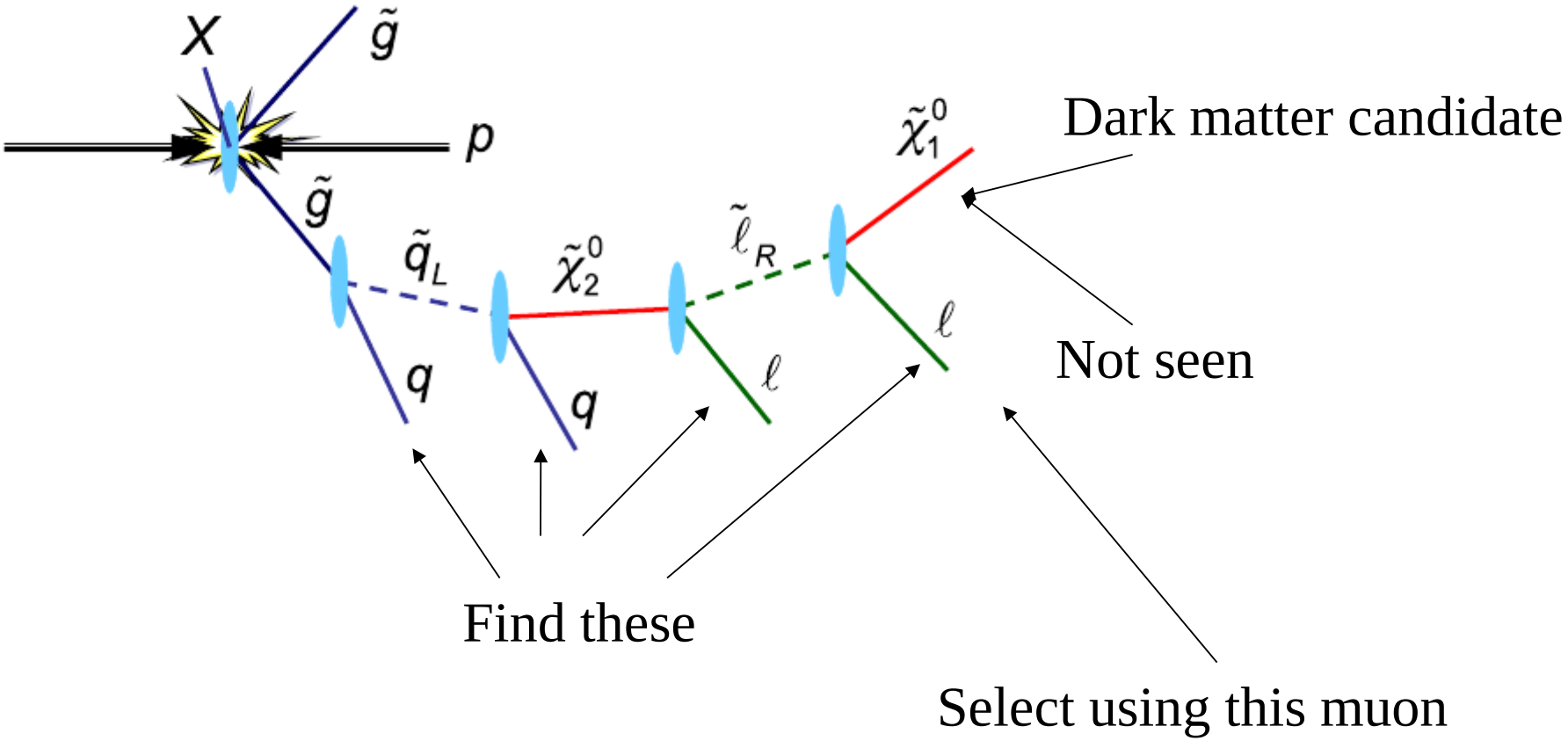
Jets (from quarks and gluons)

Missing energy (from the dark matter candidate)

Leptons

Top, bottom quarks and tau leptons may be preferred (ask a theorist)

Finding dark matter



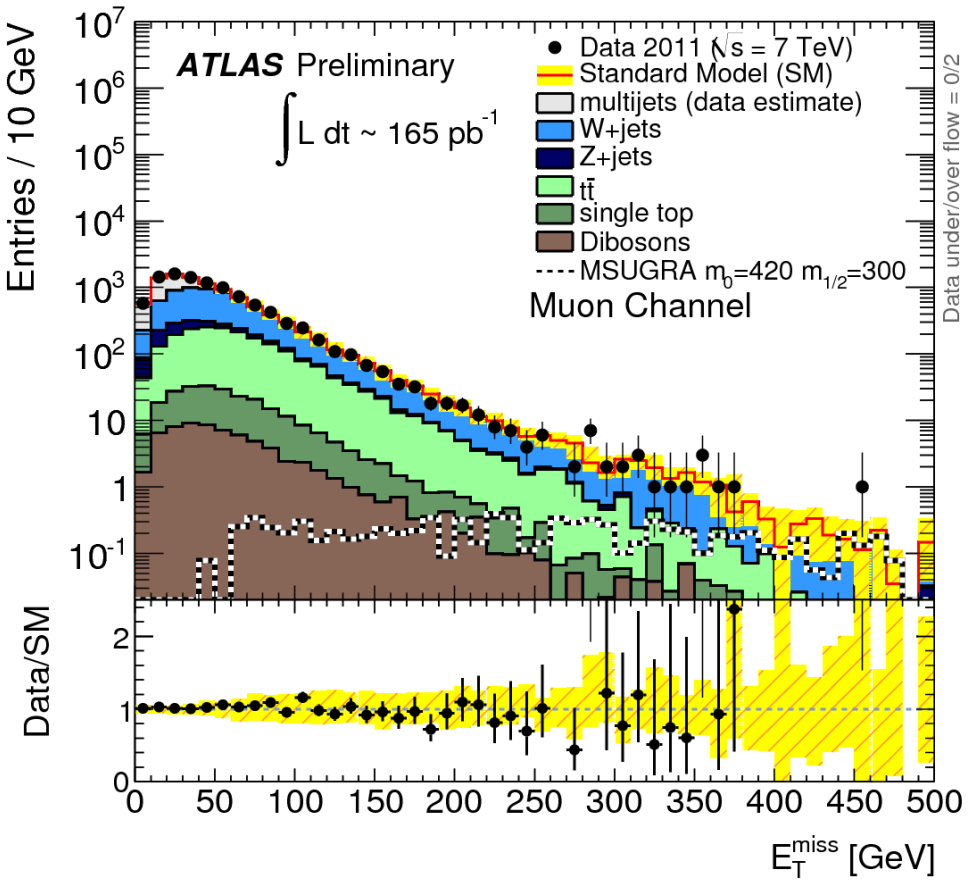
Jets, leptons, missing energy: looks a bit like top!!

Indeed it does

Event has
1 lepton
>2 jets

It's consistent with top

No susy yet!!



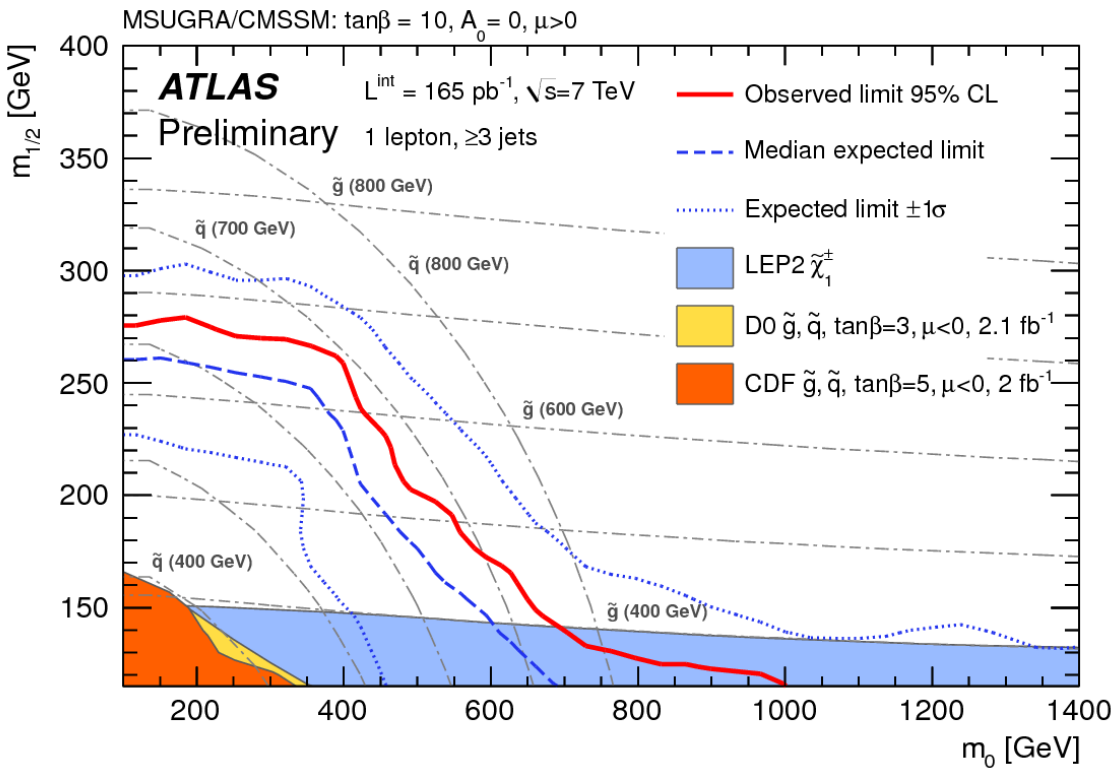
Missing energy carried off

New result

Huge increase over older experiments

Large swath of models killed

Some theorists should be nervous



SUSY models

Approx 1 model per theorist!

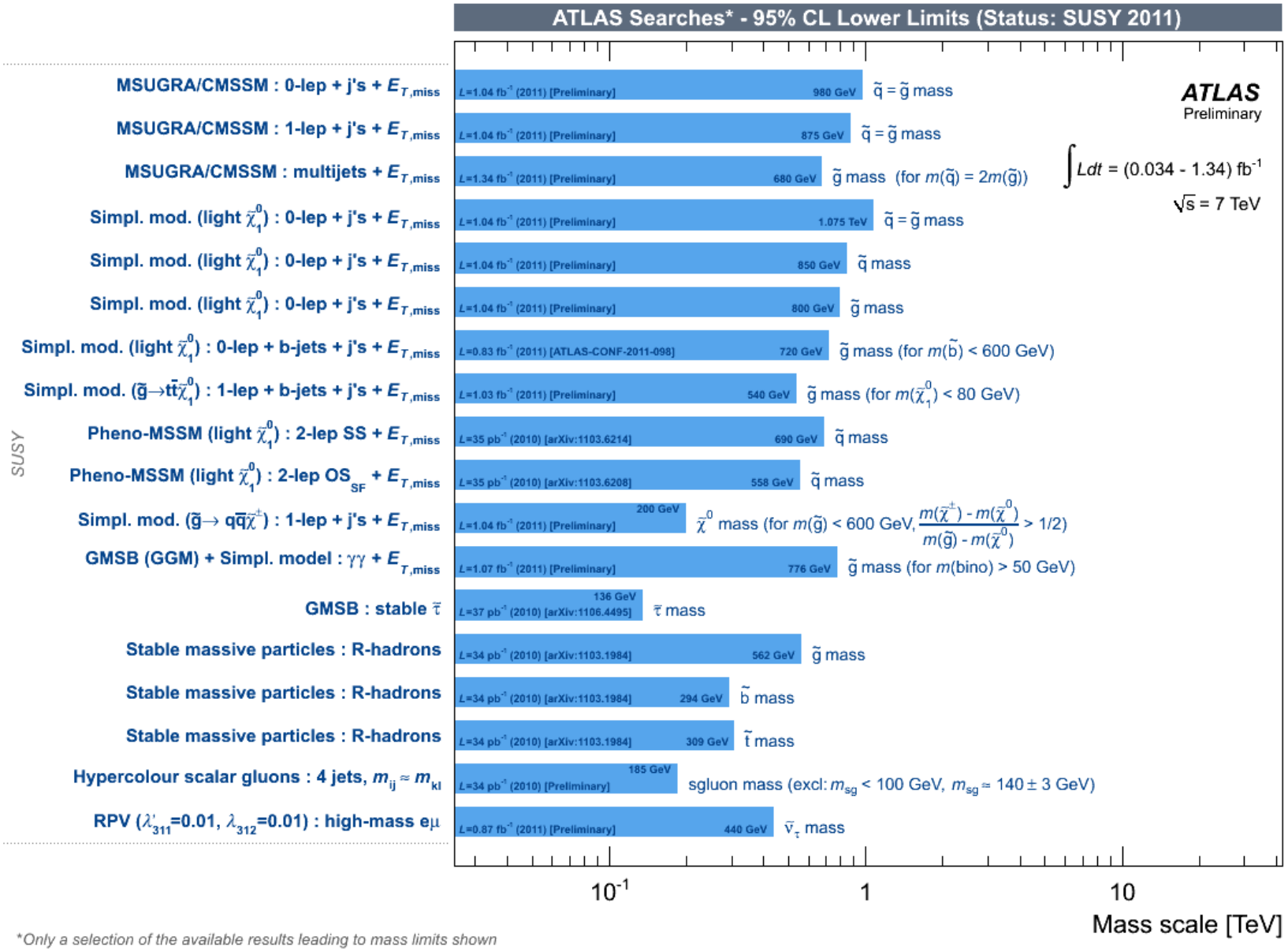
No more than one is right

Not worth the trees to rule out every one in detail

Many “generic searches”

Issue is not whether search is optimal but whether it is sensitive

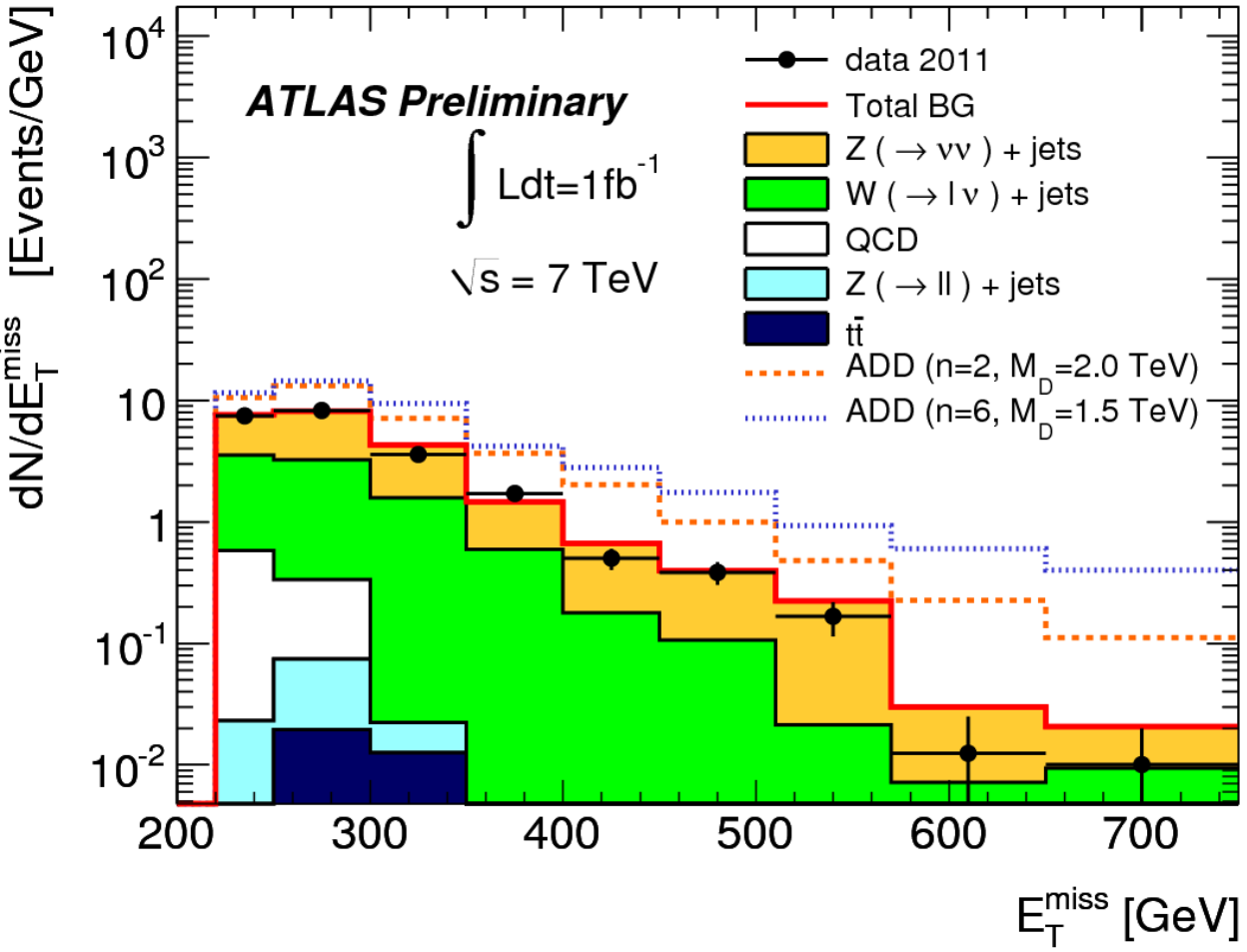
List of current limits follows (all are model dependent)



*Only a selection of the available results leading to mass limits shown

Some other examples (not susy)

Monojets (sensitive to models of extra dimensions)

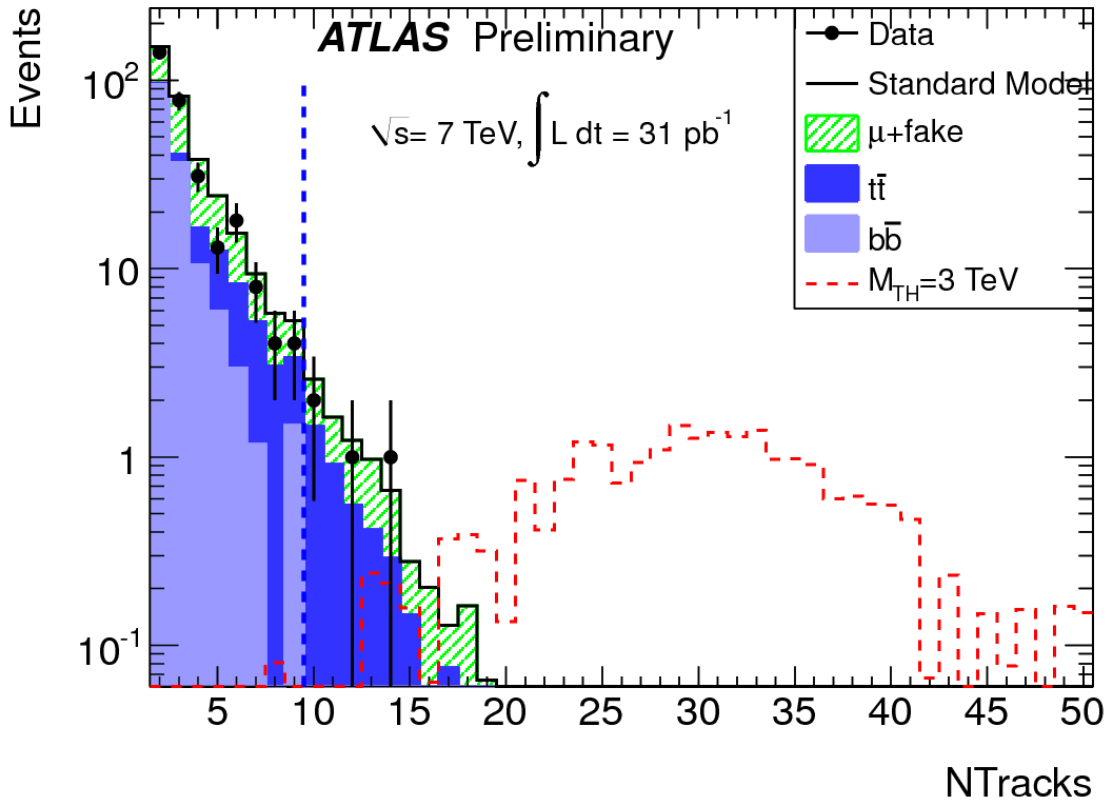


Some other examples (not susy)

Search for microscopic black hole in dimuon final states (ATLAS-CONF-2011-065) (nothing seen)

ATLAS-CONF-2011-065

Uses expected large track multiplicity

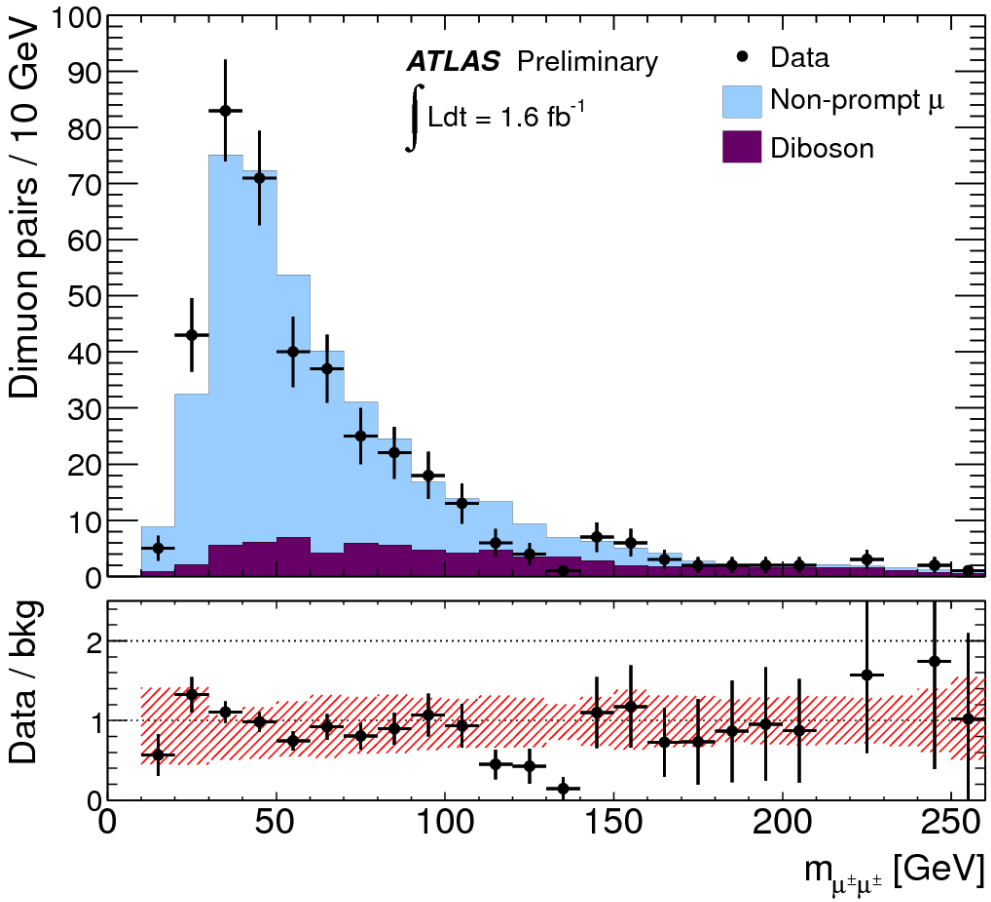


Generic search

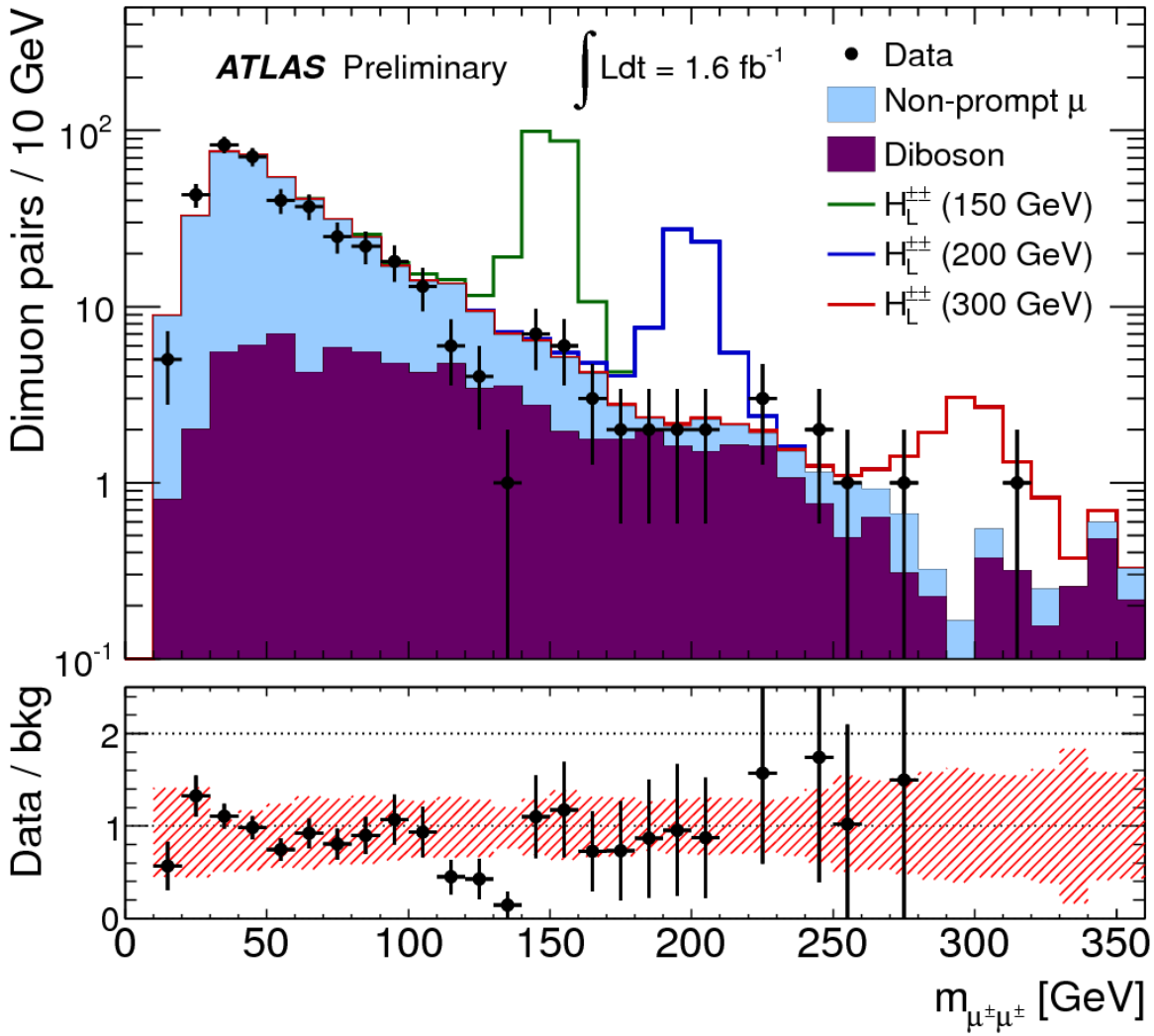
Same sign muon pairs

No signal.

This can be interpreted
In a model

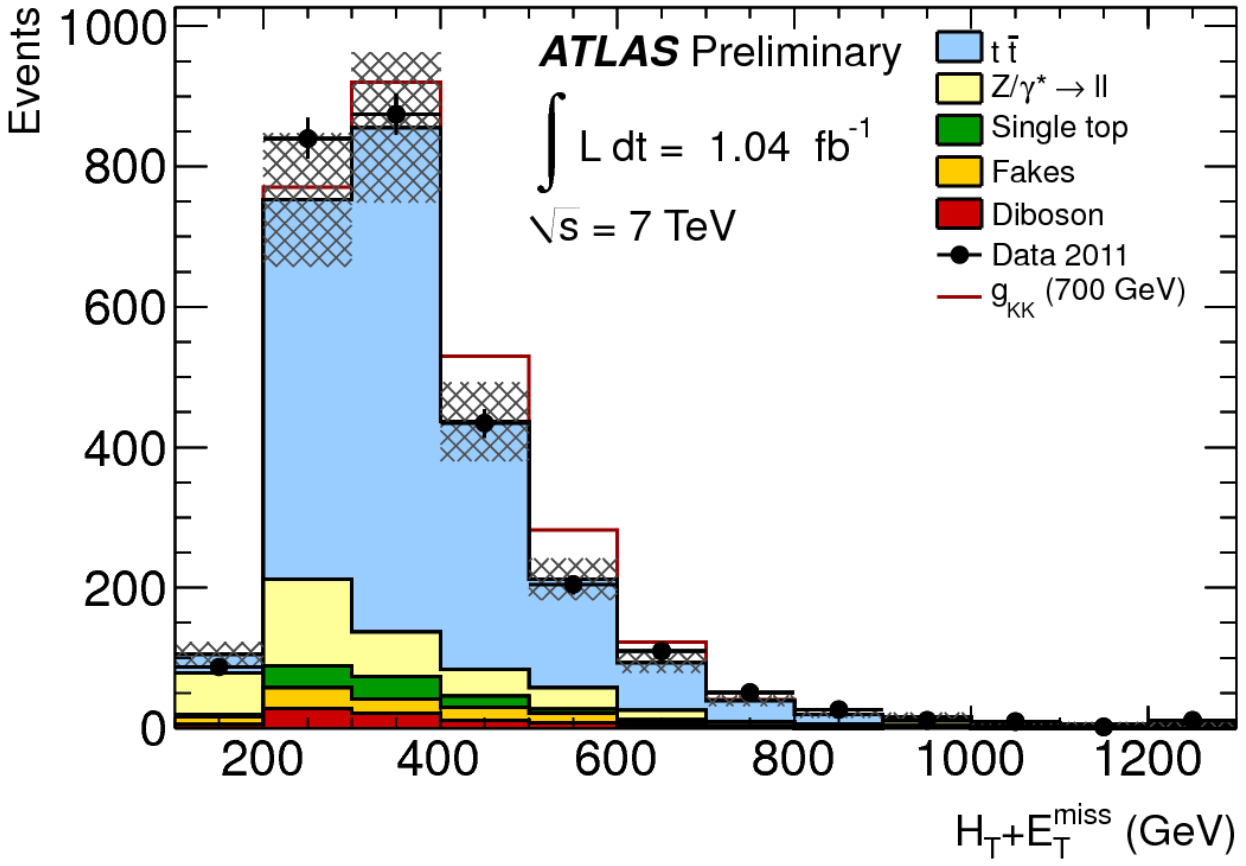


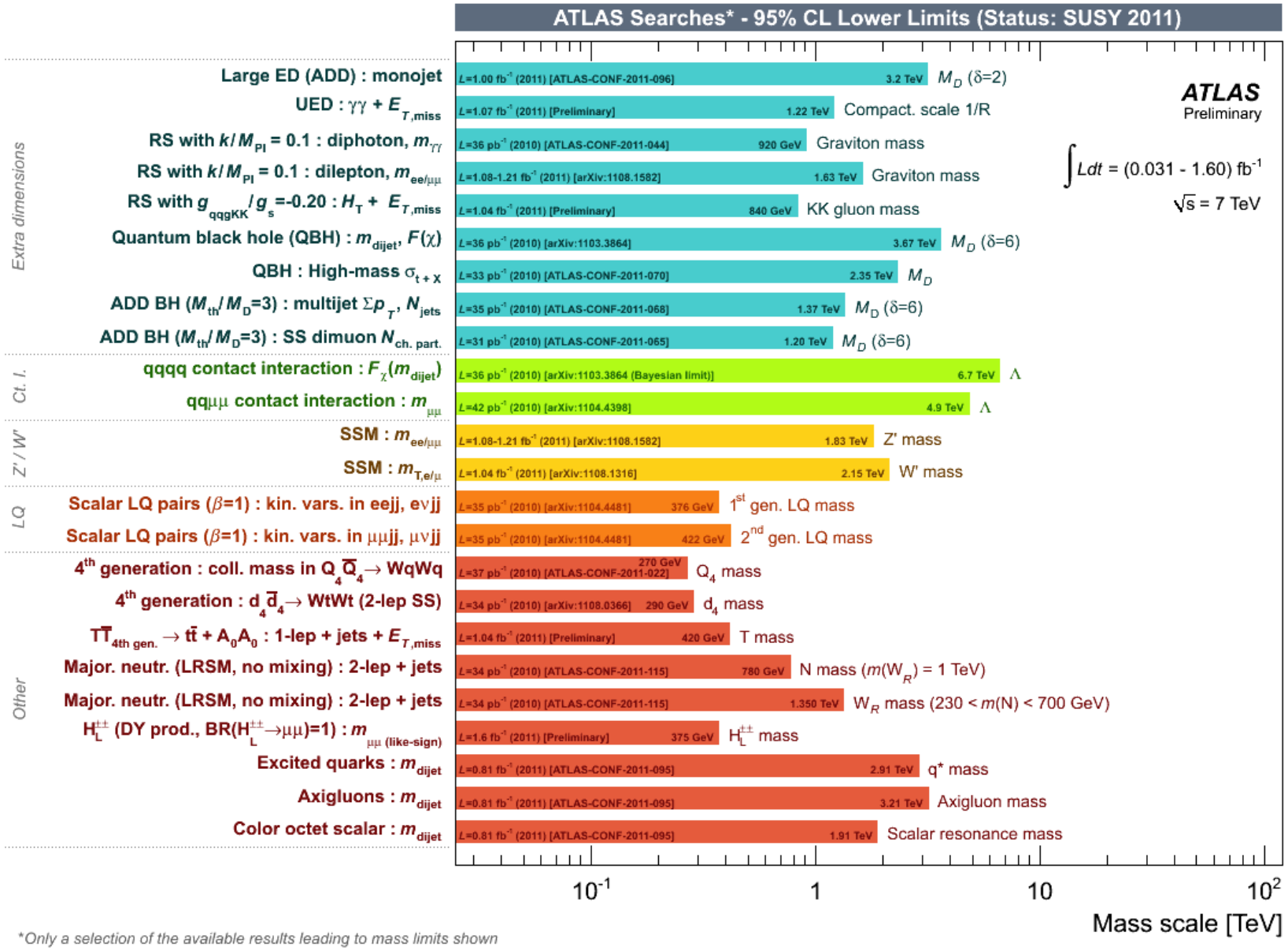
Doubly charged Higgs



Top anti-top resonances

Opposite sign, same flavor lepton pairs





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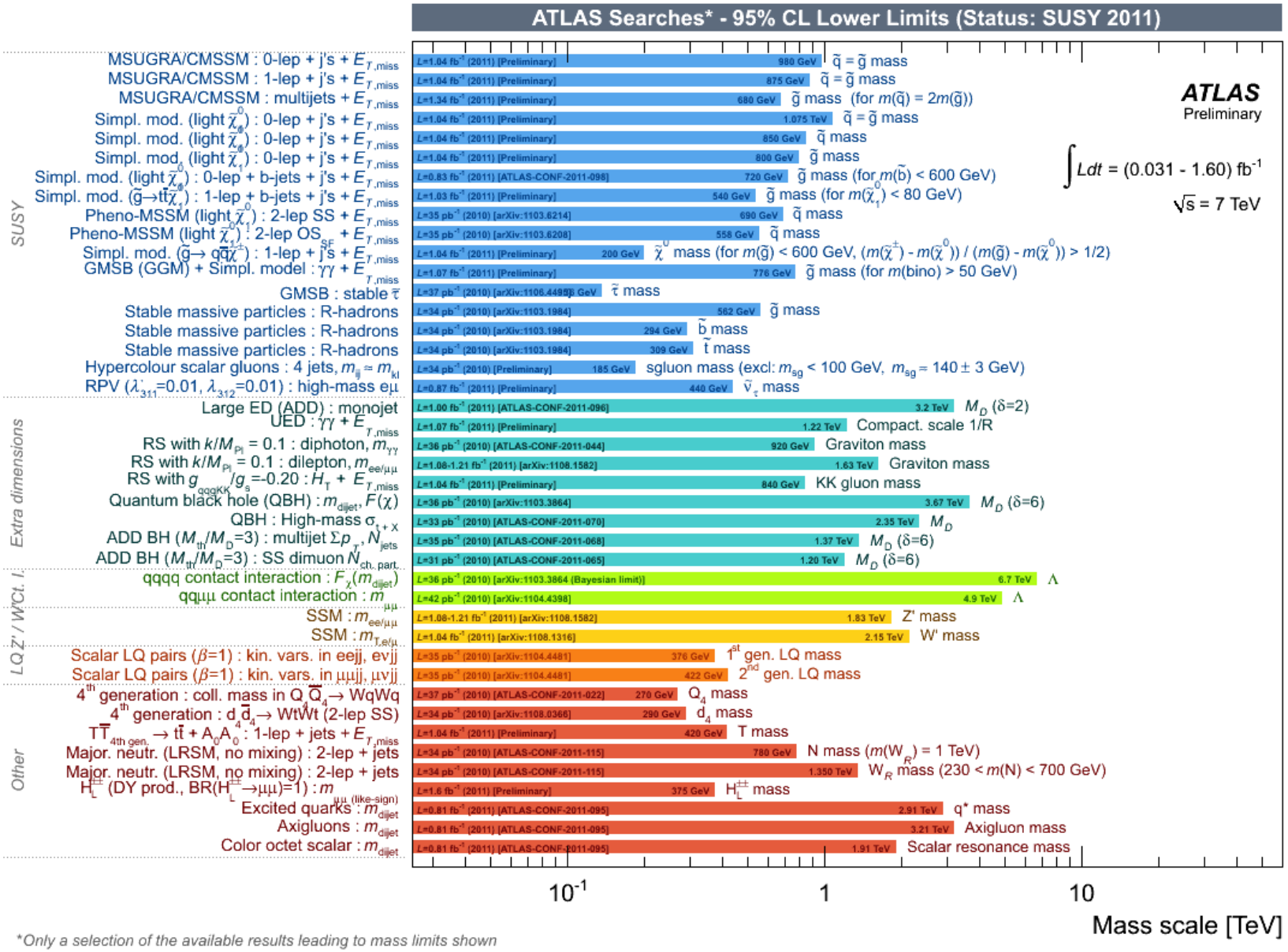

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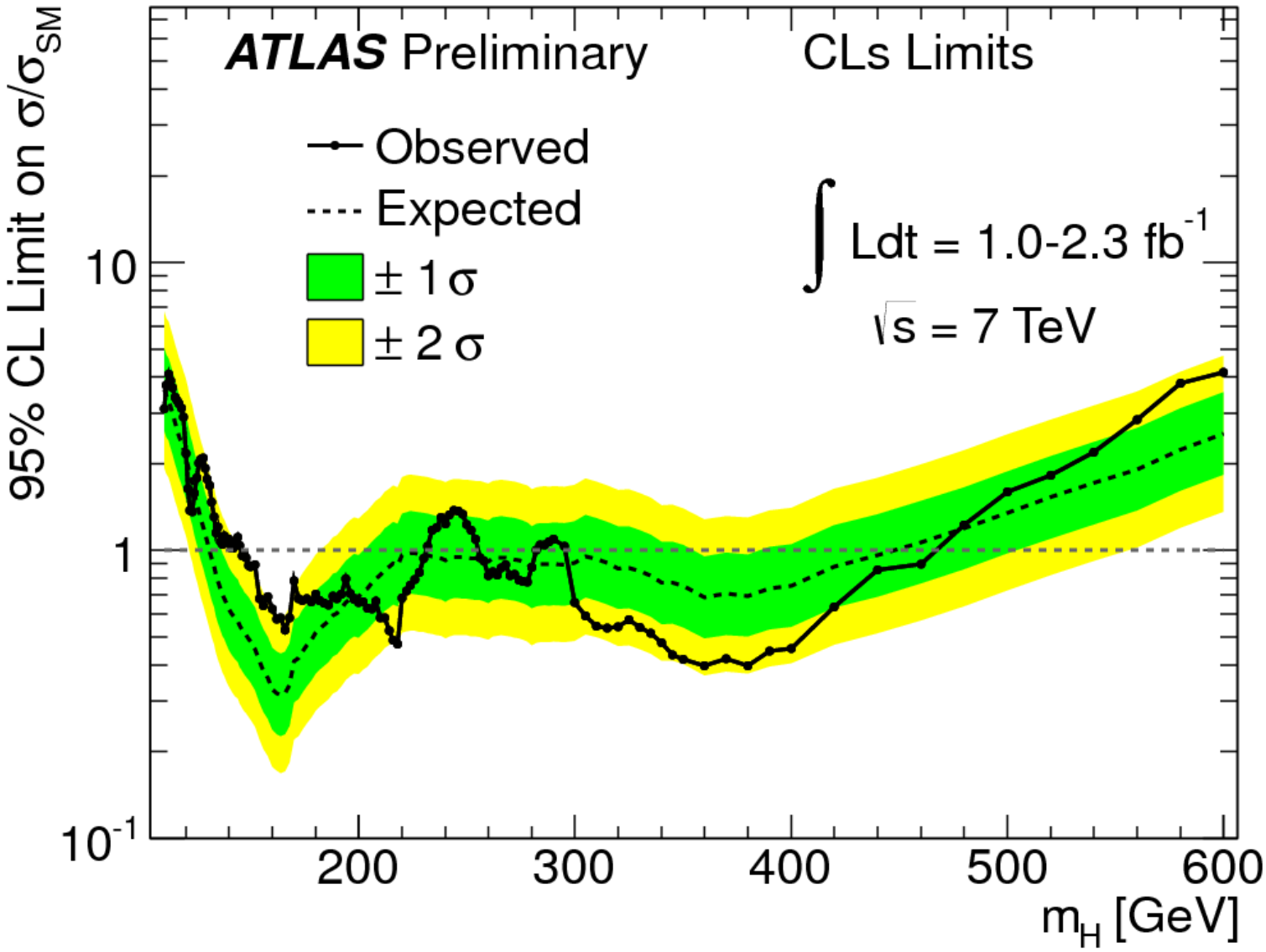
Higgs status



The future

The discovery era is beginning

- **Lots of theoretical ideas**
  - **Supersymmetric particles**
  - **Extra dimensions**
  - **..**
- **Need to know which are physics and which are sophistry**

Expect to operate LHC for 20 years

Energy will double in 2014

Intenstiy will increase by factor of 100 by 2018

Plans afoot to increase intensity by another factor of ten (2020?)

Stay tuned...